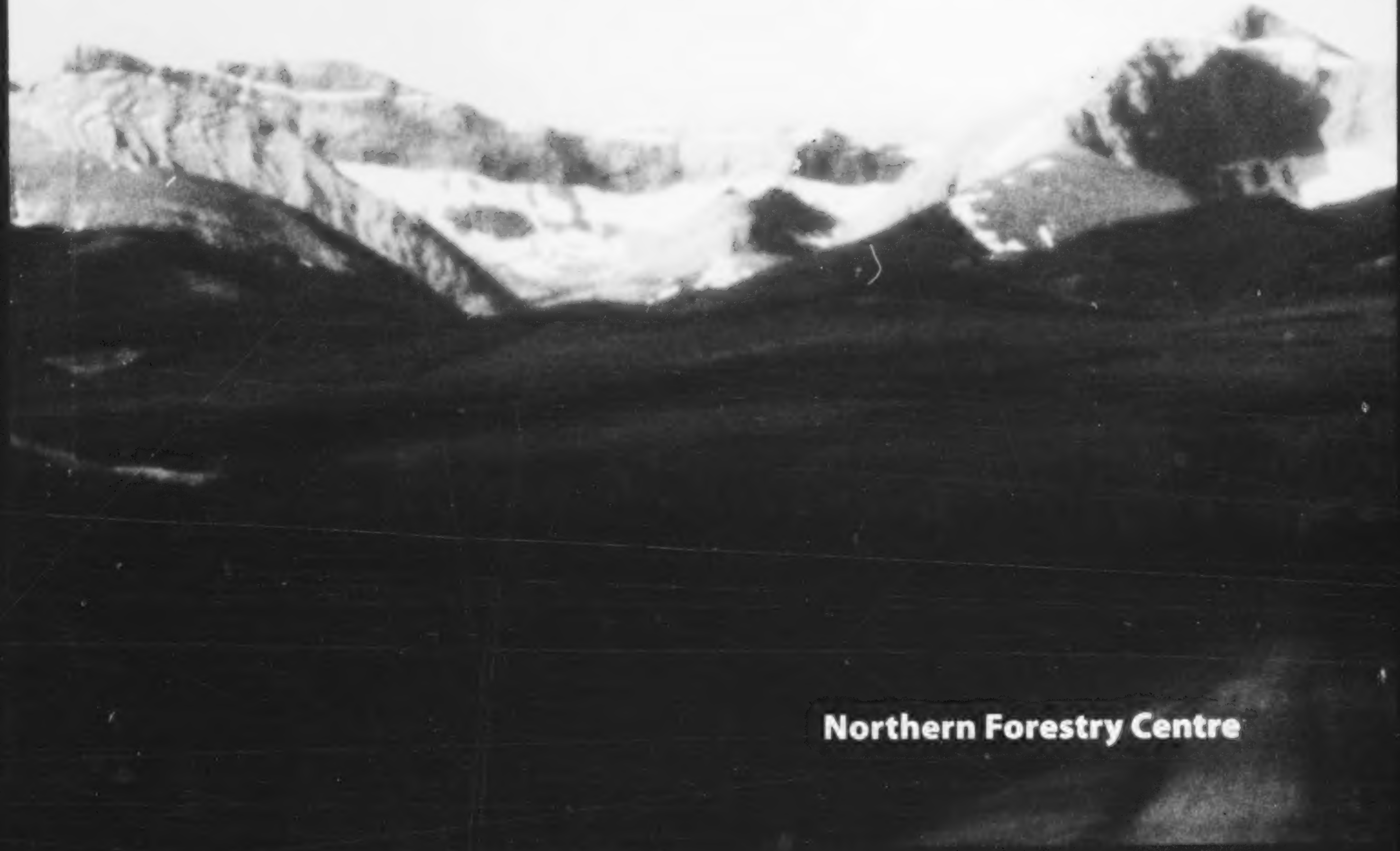
Long-term Lodgepole Pine Silviculture Trials in Alberta: History and Current Results

J.D. Stewart, T.N. Jones, and R.C. Noble



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Abstract

Long-term data from established field experiments are required to properly evaluate different silvicultural options and to provide the basis for development and validation of growth models. Such data are available from a series of thinning and fertilization field studies established between 1941 and 1984 in lodgepole pine stands in the foothills of Alberta. These field sites span a wide range of ecological conditions and geographic locations. This report describes the locations and site characteristics of these studies, their establishment histories and objectives, their experimental designs and treatments, and their results up to 2005.

RÉSUMÉ

Il est nécessaire d'obtenir des données à long terme provenant d'expériences sur le terrain pour évaluer correctement différentes approches de sylviculture et pour constituer une base de référence qui servira à l'élaboration et à la validation des modèles de croissance. De telles données peuvent être extraites des résultats d'une série d'études portant sur des campagnes d'éclaircie et de fertilisation effectuées entre 1941 et 1984 sur des peuplements de pins tordus dans les contreforts des Rocheuses, en Alberta. Ces sites couvrent une vaste gamme de conditions écologiques et d'emplacements géographiques. Le présent rapport décrit les caractéristiques des divers sites, l'historique et l'objectif de leur établissement, leur conception scientifique, les traitements qu'ils ont subis et les résultats obtenus jusqu'en 2005.

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Introduction

Long-term experimental field studies that encompass a significant portion of a rotation are needed to properly evaluate the responses of forest stands to silvicultural interventions. On the eastern slopes of the Canadian Rocky Mountains, lodgepole pine is a major economic species and is commonly grown in rotations of 70 to 150 years (Smithers 1961). Present-day silviculturists and researchers depend on the field studies established by past researchers to provide the necessary long-term data. Since 1938, the Canadian Forest Service (CFS) has established dozens of silvicultural field studies of lodgepole pine on the eastern slopes of the Rockies. These studies range from simple trials of a single thinning prescription to complex levels of growing stock installations replicated on sites of differing productivity or aspect to factorial experiments of thinning and fertilization. Although most of these studies have been discontinued for various reasons, a number remain sufficiently undisturbed and adequately documented to justify their continuation as active research sites.

In the mid-1990s, the interest of the federal and provincial forest services in pine silviculture research was at a low ebb. For most of the research trials that had been established in earlier decades, measurements were no longer being made, and information about the trials and the associated data archives were becoming dispersed. The late D. Presslee of Weldwood of Canada Ltd. (now West Fraser Timber Co. Ltd.) at Hinton, Alberta, was interested in the potential for intensive management of the foothills lodgepole pine resource and saw the historical trials as an invaluable source of knowledge for evaluating that potential. To resurrect the trials, Presslee recruited S. Lux of the Northern Forestry Centre of the CFS and S. Navratil of Silfor Consulting to help locate the field plots and collect the archival material. Weldwood funded the measurements for many of these trials in 1996 and 1997.

The most visible outcome of this activity was a series of field tours of the sites of the historical pine silviculture trials in 1999 and 2001 for representatives of the Alberta forest industry, the CFS, and Alberta Sustainable Resource Development, Public Lands and Forests Division (PLFD). The tours showcased the research and presented results from decades of measurements, including the most recent of those measurements. The tours generated a great deal of interest in the studies among the participants. Discussions during the third tour, in 2001, raised the issues of how to protect the field sites and how to extract the benefits of such long-term research. From these discussions arose the idea of cooperative management of the trials by industry and the research and regulatory communities. Following a series of meetings, an agreement for collaborative management was signed in July 2002 by the newly established Foothills Growth and Yield Association, the CFS, and the PLFD. The agreement defined roles and activities related to ongoing protection, maintenance, measurement, data analysis, and data interpretation associated with these trials.

Most of the studies were established independently of each other, by different researchers, for different purposes. However, collectively they have generated substantial information on the range of response of lodgepole pine stands to density management. As such, they represent a valuable and indispensable legacy of long-term results that will be useful in the management of lodgepole pine on the eastern slopes of the Rocky Mountains. Examining these long-term results will aid in understanding the responses of lodgepole pine to silvicultural treatments and in developing silvicultural practices that are most appropriate for this region and species.

This report is a compilation of the establishment information, site descriptions, and current results from 12 long-term thinning, spacing, and fertilization studies established on the eastern slopes of the Canadian Rocky Mountains.

Methods

The sites and a brief description of the treatments for each of the long-term silviculture studies are listed in Table 1. Seven of the studies use some form of density control as the main treatment, two studies examine the effects of fertilization in previously thinned stands, and three use factorial combinations of fertilization and thinning. The trials were established between 1941 and 1984 in fire-origin stands. Table 2 depicts the range of site nutrient and moisture conditions in these lodgepole pine stands. Site classifications for the southwest region were derived using *Field Guide to Ecosites of Southwestern Alberta* (Archibald et al. 1996), and classifications for the west central sites were derived from *Field Guide to Ecosites of West-Central Alberta* (Beckingham et al. 1996).

Plot (ecological site classification) and tree (height and diameter) data from these trials were compiled from paper and electronic archival sources and recent remeasurements; the data were merged into a common electronic database. If tree heights had not been measured, they were estimated from provincial height–diameter equations (Huang 1999) using coefficients estimated for individual treatments in each trial for lodgepole pine (R.C. Yang, Forest Mensurationist, Northern Forestry Centre, Canadian Forest Service, unpublished data) and coefficients estimated for the Lower Foothills Natural Subregion for other species (Huang 1999). Before compilation for analysis, the data were screened for obvious errors (e.g., shrinking height or diameter measurements) and, where possible, such errors were corrected.

The periodic rate of mortality was calculated as the number of dead trees at the end of a measurement interval divided by the number of live trees at the start of the interval. Annual mortality was calculated by dividing periodic mortality by the number of years between the two measurements and is expressed as a percentage.

Total and merchantable volumes were calculated for each tree at each measurement time, using equations developed for lodgepole pine in Alberta by PLFD (Huang 1994). Total volume was calculated as total residual live-stem volume inside bark (1.25 cm top diameter and 30 cm stump height). Merchantable volumes were calculated according to two utilization standards commonly used in Alberta, 13/7 and 15/10, the first number referring to the diameter in centimeters outside the bark at stump height (30 cm) and the second number referring to the diameter in centimeters inside the bark at the top, with a minimum merchantable length of 2.44 m (Huang et al. 2001). Data for surviving trees were aggregated by plot and treatment and were converted to a per hectare basis.

In the following sections, results for individual tree (crop tree) growth and mortality refer to only those trees that were tagged and measured at the initiation of each installation. Stand development results are for all trees in the plots, including species other than pine and ingrowth trees that were tagged after the first measurement. Diameter refers to diameter at breast height.

The scientific names of plant species mentioned in this report are provided in Appendix 1. Access maps showing the location of trials in the Kananaskis, Hinton, MacKay and Rocky Mountain House regions are provided in Appendix 2. The plot layouts for each site are presented in Appendix 3. Tables of top heights for each study are presented in Appendix 4, and stand density management diagrams comparing the studies are presented in Appendix 5.

Table 1. Summary of active long-term lodgepole pine stand density and fertilization trials in Alberta included in this report

Trial name	Year established	Type	Treatments
K-57	1941	Density control	Thinning from above and below at stand age of 77 years
Strachan	1951	Density control	Three improvement cuts at stand age of 85 years
MacKay	1954	Density control	Thinning (4 levels) at stand age of 22 years, plus rethinning (1 level) at stand age of 37 years
Gregg 1963 low productivity site	1963	Density control	Juvenile spacing (5 levels) at stand age of 7 years
Gregg 1963 medium productivity site	1963	Density control	Juvenile spacing (5 levels) at stand age of 7 years
Gregg 1963 high productivity site	1963	Density control	Juvenile spacing (5 levels) at stand age of 7 years
Ricinus	1965	Fertilization	Three levels of fertilization at stand age of 15 years in a previously thinned stand
Teepee Pole flat site	1967	Density control	Spacing (5 levels) at stand age of 25 years
Teepee Pole north site	1967	Density control	Spacing (5 levels) at stand age of 25 years
Teepee Pole south site	1967	Density control	Spacing (5 levels) at stand age of 25 years
Clearwater	1968	Fertilization	Three-way randomized incomplete factorial of fertilization with N, P, and S (3 levels each) applied at stand age of 72 years in a previously thinned stand
Swan Lake	1976	Density control	Mechanical thinning with 3 scarification implements at stand age of 9 years
Takyi 7008	1980	Fertilization and thinning	Three-way factorial of thinning (3 levels), fertilization (4 levels), and 2 N sources at stand age of 24 years
Takyi 7009	1980	Fertilization and thinning	Two-way factorial of thinning (3 levels) and fertilization (3 levels) at stand age of 24 years
Gregg 1984 low productivity site	1984	Density control	Spacing (4 levels) at stand age of 28 years
Gregg 1984 medium productivity site	1984	Density control	Spacing (4 levels) at stand age of 28 years
Gregg 1984 high productivity site	1984	Density control	Spacing (4 levels) at stand age of 28 years
McCardell	1984	Fertilization and thinning	Two-way factorial of thinning (2 levels) and fertilization (4 levels) at stand age of 40 years

Table 2. Distribution of trials within the edatopic grid

	Ecological soil nutrient regime		
Ecological soil moisture regime	B (poor)	B–C (poor–medium)	C (medium)
4 (submesic)	Gregg 1963 low	NA	Teepee Pole south
4–5 (submesic-mesic)	NA[a]	Strachan	K-57
5 (mesic)	Gregg 1963 medium Gregg 1984 low MacKay Takyi 7009	Clearwater Gregg 1984 medium McCardell	Gregg 1984 high Teepee Pole flat Teepee Pole north Ricinus Takyi 7008
5–6 (mesic-subhygric)	NA	NA	Gregg 1963 high Swan Lake

[a] NA = not applicable.

Kananaskis Commercial Thinning Trial, Project K-57 (1941)

Location and Access

The K-57 trial site is located in the Kananaskis Valley, southwest Alberta (50°59.0'N, 115°4.5'W, legal location 29-23-8-W5). To access the trial site, travel to the junction of Highway 1 and Highway 40 (82 km west of Calgary, 26 km east of Canmore), and follow these directions:

Turn south on Highway 40 toward Kananaskis Village.

Continue past the junction with Highway 68 (at kilometre 7.5).

Continue past the turn-off to the Porcupine Creek Group Campground (on the right-hand side at kilometre 14.5).

Travel 600 m farther to reach tie point A (flagging on both sides of Highway 40 at kilometre 15.1).

Establishment and Objectives

The K-57 trial began in 1941 as one of a series of pine silviculture trials established by the Kananaskis Forest Experiment Station of the Dominion Forest Service in the Kananaskis Valley. Initially regarded as an operational trial, K-57 later became the foundation of an empirical experiment conceived by J. Quaite to determine the effects of thinning on lodgepole pine growth (Quaite 1949). The objective of this trial was to commercially thin a mature, overstocked lodgepole pine stand for fuelwood with the intention of producing poles and sawlogs after a second thinning (Quaite 1950). However, the final thinning, originally planned for about 1970 (Quaite 1949), never took place. Following the establishment report by Quaite (1949), several reports based on remeasurements of the stand have been published (Quaite 1950, 1955; Johnstone 1982a; Navratil 2002).

Site Description

The K-57 trial site is located in southwestern Alberta, close to a convergence of the Montane, Lower Foothills, and Subalpine subregions, but it was found to most closely match the MN C2.1, lodgepole pine/Canada buffalo-berry/hairy wild rye plant community type (Geographic Dynamics Corp. 1999). It is located at an elevation of 1371 m on degraded brown-wooded soil that has developed on fine-textured deltaic and alluvial fan deposits with moderately high lime content (Johnstone 1982a). This site has a submesic to mesic moisture regime and a medium nutrient regime. The trial was established in a 77-year-old overstocked lodgepole pine stand (>85% pine by volume) with a significant proportion of white spruce and some aspen in the understory (Quaite 1949; Johnstone 1982a). The stand originated after an 1864 wildfire (Quaite 1949). In summer 1941, the average density of all trees was 7163 stems per hectare, average diameter was 9.1 cm (Quaite 1950), and the maximum height of the pine trees was about 17 m (Johnstone 1982a).

Experimental Design and Treatments

A combination of heavy thinning (70% of volume removed) from above and below (Quaite 1950; Johnstone 1982a) resulted in a stand density of 1710 stems per hectare and an average diameter of 10.2 cm. The density of lodgepole pine was 1554 stems per hectare with an average diameter of 10.7 cm (Quaite 1950). Research plots established in 1949 consisted of four 0.08-ha measurement plots in the thinned stand and two 0.04-ha plots in an adjacent unthinned area. Quaite (1955) observed that the control plots appeared to have been established on better sites than the treatment plots. All living trees were tagged and measured for diameter at breast height, and height was measured on a subsample of the tagged trees.

Trees in the plots were remeasured in 1953, 1963 and 1999, and are scheduled for remeasurement again in 2006.

Results after 58 Years

The results focus on data from the available field measurements from 1949, 1963, and 1999; data summaries from 1941 are presented when available.

Tree Growth and Mortality

From 1949 to 1999 fewer crop trees died in the thinned stand than in the unthinned (control) plots (Fig. 1). Pine mortality during the initial 14-year period averaged 3% per year in the unthinned plots, but only about 0.4% per year in the thinned plots. Over the next 36-year interval, mortality in the unthinned plots dropped dramatically, to 0.7% per year, but cumulative mortality was still more than twice that in the thinned plots. Mortality rates for spruce were lower than those for pine; however, mortality was still greater in the unthinned plots. No spruce trees died in the thinned plots over the 36-year interval between 1963 and 1999.

Average diameter in the treatment stand increased by about 1.3 cm after thinning (Fig. 2). From the time measurement plots were established in 1949 until 1999, pine crop trees in the thinned stand had a lower rate of diameter growth (57%) than those in the unthinned stand (73%). However, the absolute diameter increment was similar in the thinned and unthinned plots. The major difference was in the response of spruce trees. In the control plots, spruce diameter development paralleled that of pine. In the thinned plots, understory spruce took advantage of the extra growing space, and average diameter increased from 5 cm to 19 cm, making them nearly the same size as the pine.

Average height growth was similar in the thinned and the control plots. Pine trees in the two stands were the same height in 1949, and at the end of the measurement period (in 1999), trees in the thinned plots were only about 0.6 m taller than those in the unthinned plots (Fig. 3). Spruce in the control plots grew at about the same rate as pine, whereas spruce in the thinned plots grew much faster than pine. In the thinned plots, the spruce started out in the understory at a height of about 4 m. By 1999, they had become codominant, with an average height about 1 m shorter than the pine trees.

Stand Development

Stand density in the control plots decreased by almost two-thirds over 50 years; the thinned plots showed a lower rate of decline, with a reduction by about one-third of the original density (Fig. 4). Most of the mortality in the thinned plots, and to a lesser extent in the unthinned plots, was of the pine component; relatively few of the spruce trees died. The initial thinning intensity was heavy, and as a consequence, even after 58 years of growth and mortality, there was still a large difference in stand density between the thinned and unthinned plots.

As a consequence of the thinning performed in 1941, the pine showed a strong shift in diameter distribution. The thinned plots had a greater proportion of larger diameter pines than the unthinned plots (Fig. 5). This shift in diameter distribution was even more pronounced for spruce. The height–diameter relationships appeared to be the same for trees in both the thinned and control plots; however, the spruce appeared to have lower height–diameter ratios than the pine (Fig. 6).

From 1949 to 1999, basal area doubled in the thinned stand, but there was an increase of only 11% in the unthinned stand (Fig. 7). In the thinned plots, pine contributed most of the basal area growth, although spruce contributed an increasing proportion. In contrast, in the control plots, pine basal area decreased significantly because of tree mortality, but this was more than offset by the increase in spruce basal area.

Total volume increment rates between 1949 and 1999 were much higher for the thinned plots than for the control plots, although the latter maintained greater volume in 1999. This outcome is likely due to the intensity of thinning and the late stand age (77 years) at which thinning was carried out (Fig. 8). As for basal area, most of the volume increment in the control plots was attributable to the spruce component, whereas pine was the major volume contributor in the thinned plots. Pine volume in the thinned plots exceeded that in the control plots in 1999. Summing the volume removed by thinning (187 m^3/ha) and the standing total volumes presented here showed that there was greater cumulative volume production for the thinned plots than for the unthinned plots.

There were steady increments in merchantable volume (for both the 13/7 and 15/10 standards) over time for both the thinned and the unthinned stands, with values for the thinned stand slowly converging with those of the control stand (Figs. 9 and 10). Trends were similar to those for total volume. The 13/7 merchantable volume removed at thinning was estimated at about 85 m^3/ha. Although the merchantable volume was higher in the control stand 58 years after thinning, the cumulative merchantable volume (standing volume + removed volume) was slightly higher for the thinned stand than for the unthinned one.

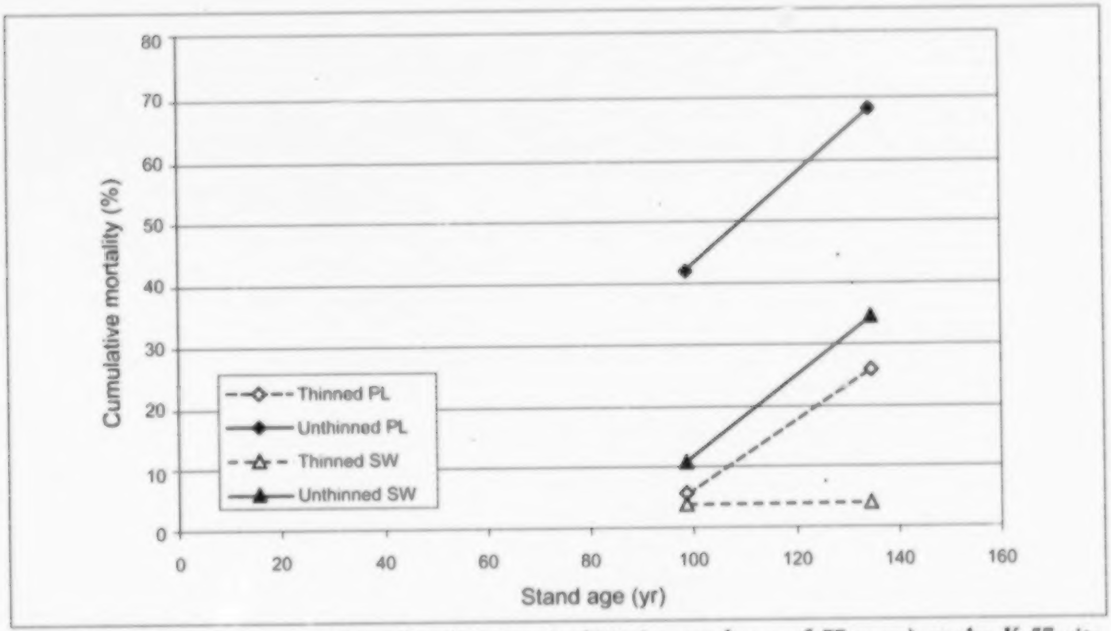

Figure 1. **Cumulative mortality after thinning in 1941 (at stand age of 77 years) at the K-57 site.** PL = lodgepole pine, SW = white spruce.

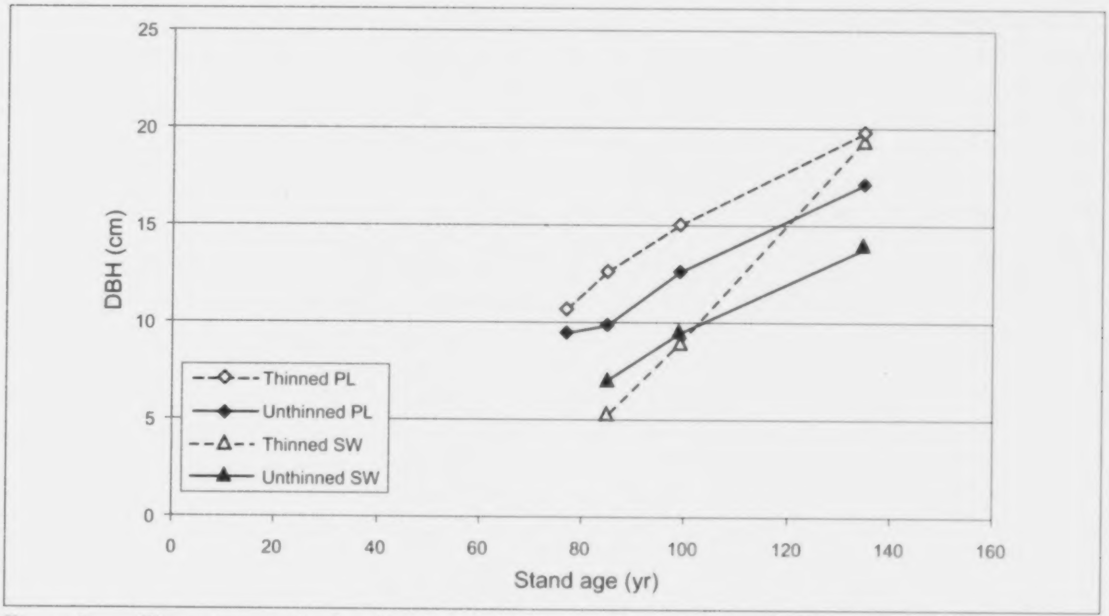

Figure 2. **Diameter growth after thinning in 1941 (at stand age of 77 years) at the K-57 site.** DBH = diameter at breast height, PL = lodgepole pine, SW = white spruce.

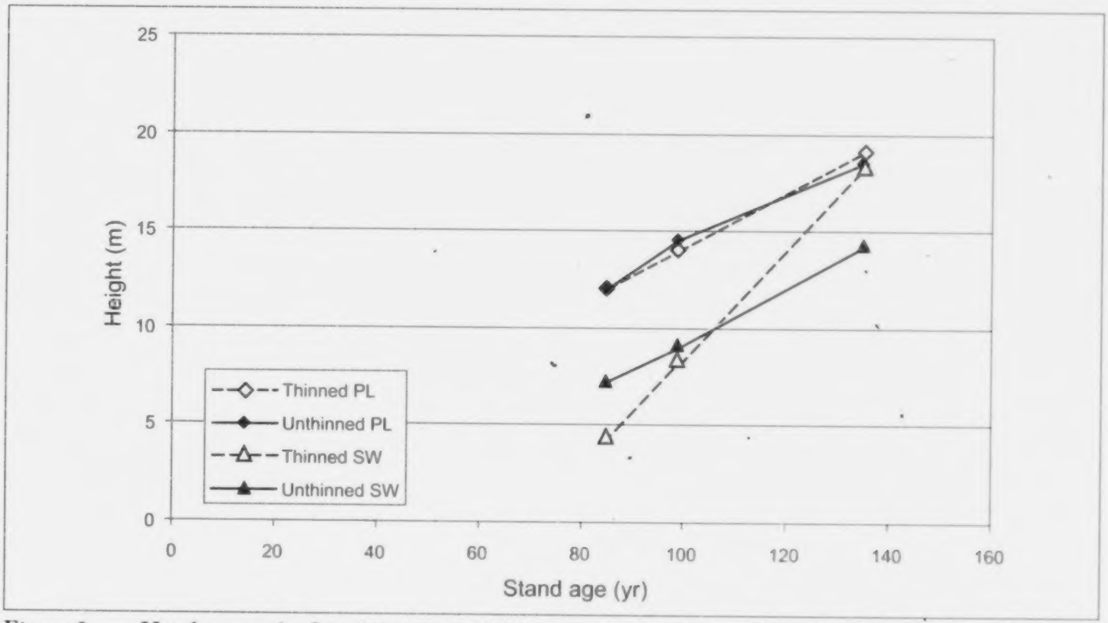

Figure 3. **Height growth after thinning in 1941 (at stand age of 77 years) at the K-57 site.** PL = lodgepole pine, SW = white spruce.

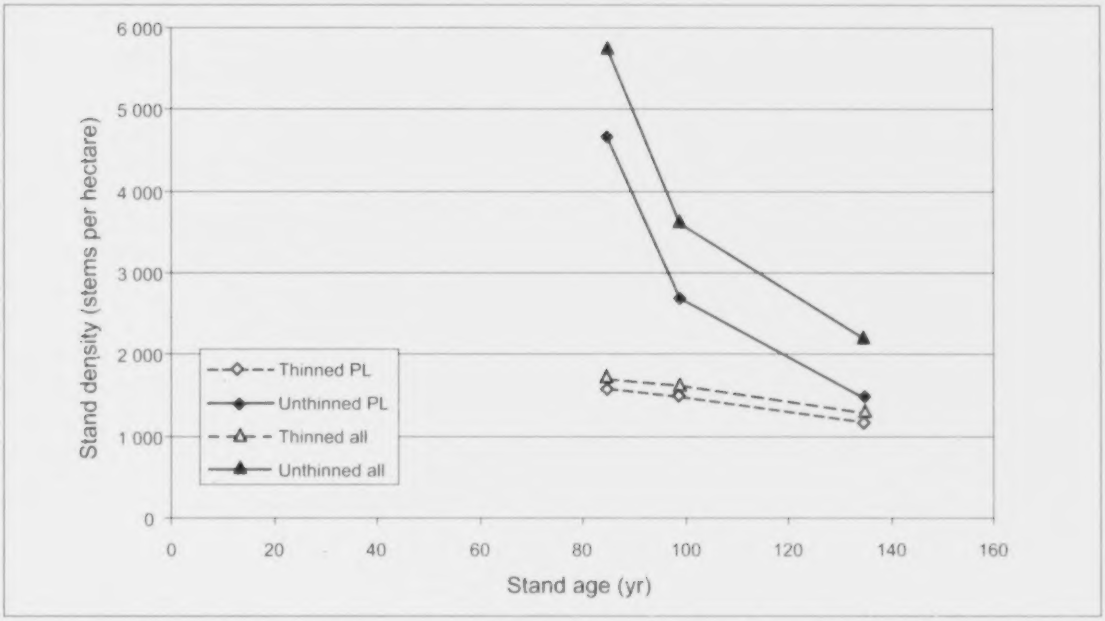

Figure 4. **Stand density development after thinning in 1941 (at stand age of 77 years) at the K-57 site.** PL = lodgepole pine.

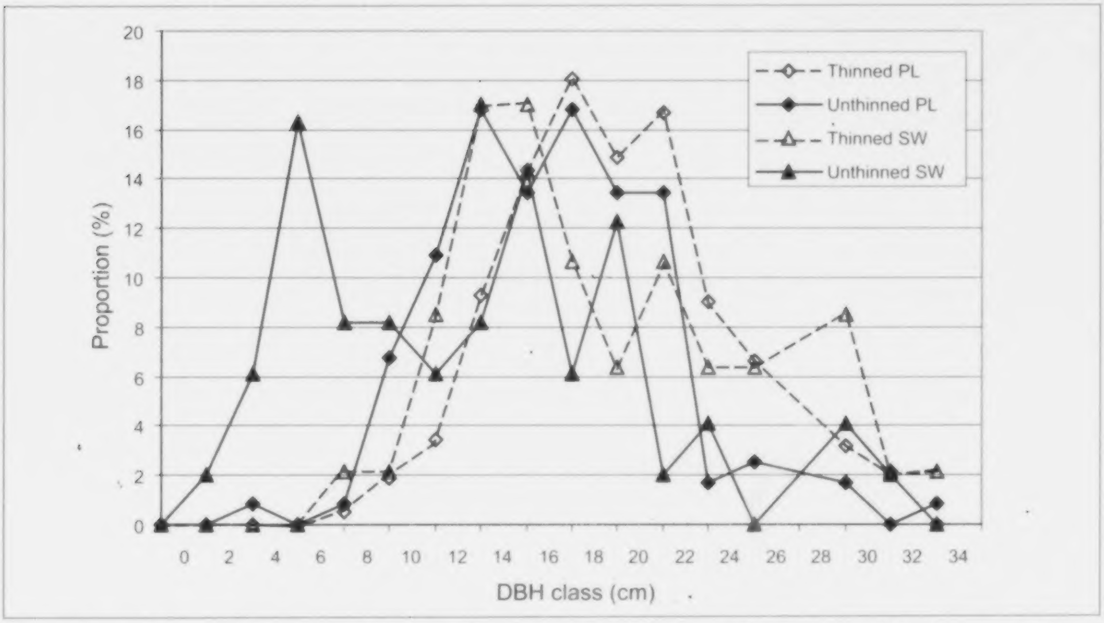

Figure 5. **Diameter distribution 58 years after thinning in 1941 in the K-57 trial.** DBH = diameter at breast height, PL = lodgepole pine, SW = white spruce.

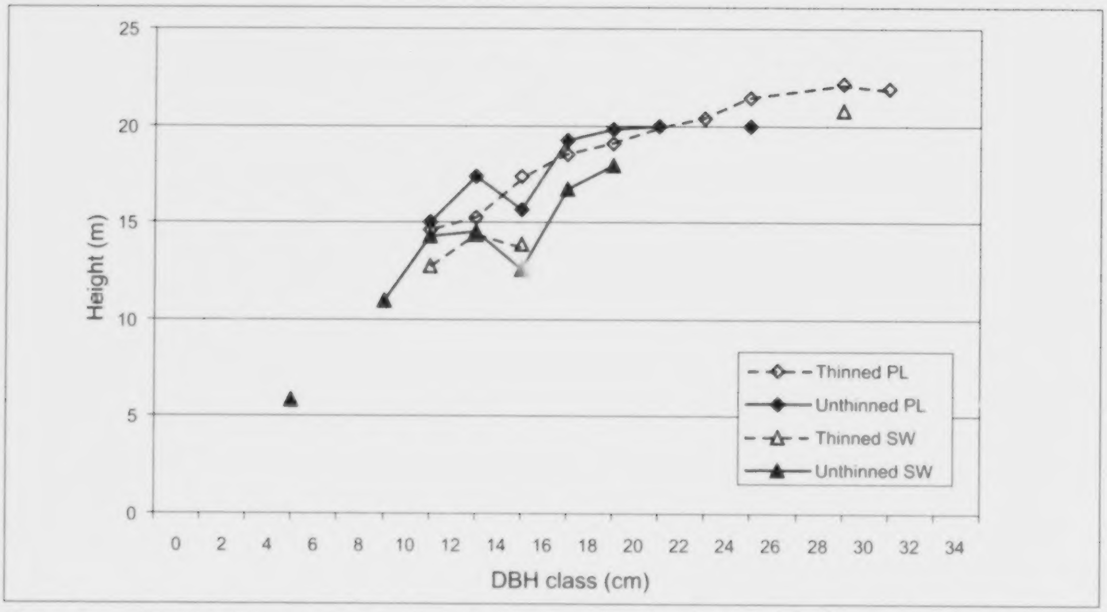

Figure 6. **Height–diameter relationships 58 years after thinning in 1941 in the K-57 trial.** DBH = diameter at breast height, PL = lodgepole pine, SW = white spruce.

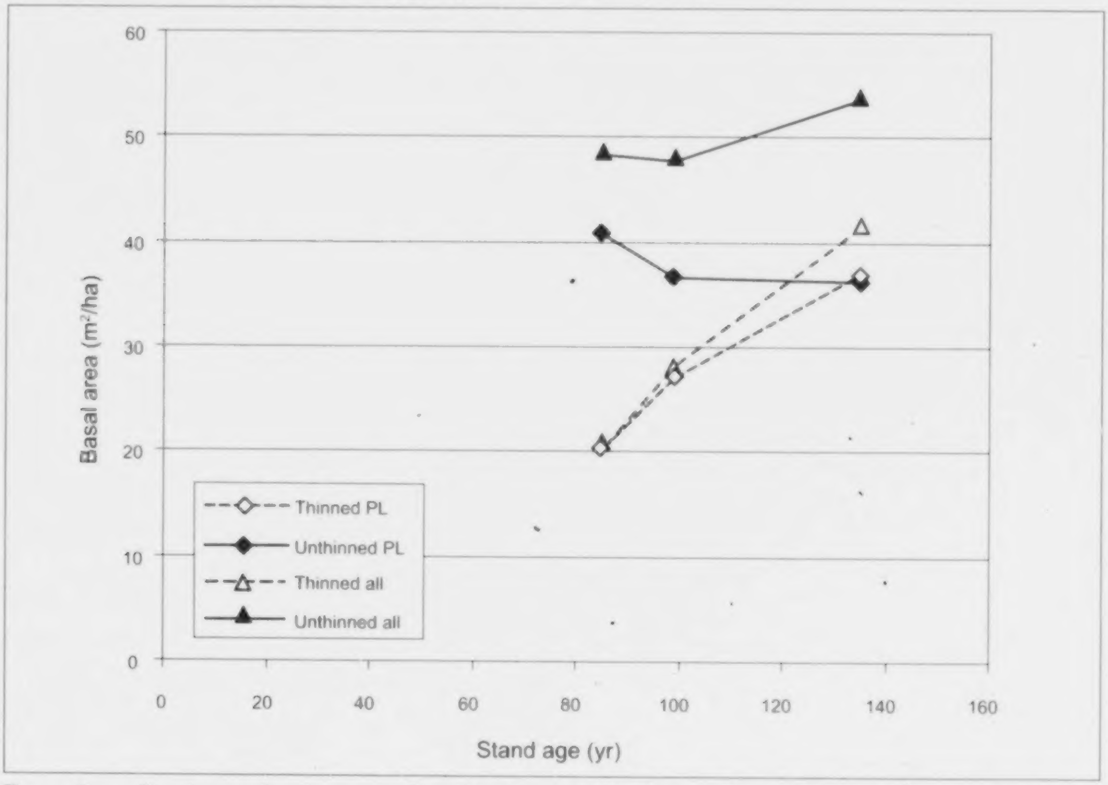

Figure 7. **Basal area development after thinning in 1941 (at stand age of 77 years) at the K-57 site.** PL = lodgepole pine.

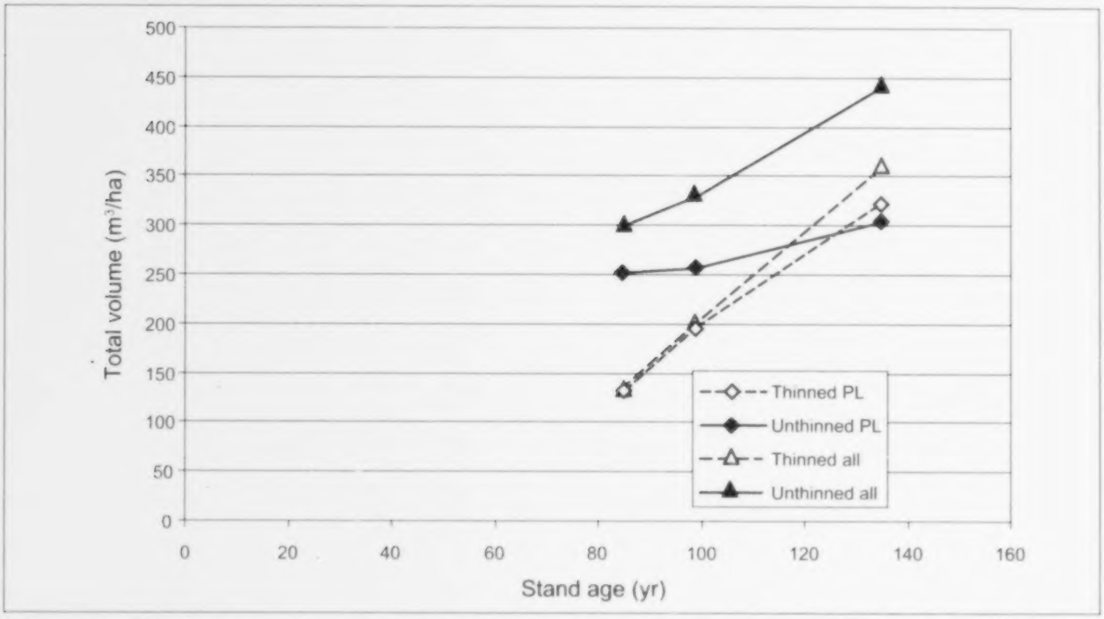

Figure 8. **Total volume development after thinning in 1941 (at stand age of 77 years) at the K-57 site.** PL = lodgepole pine.

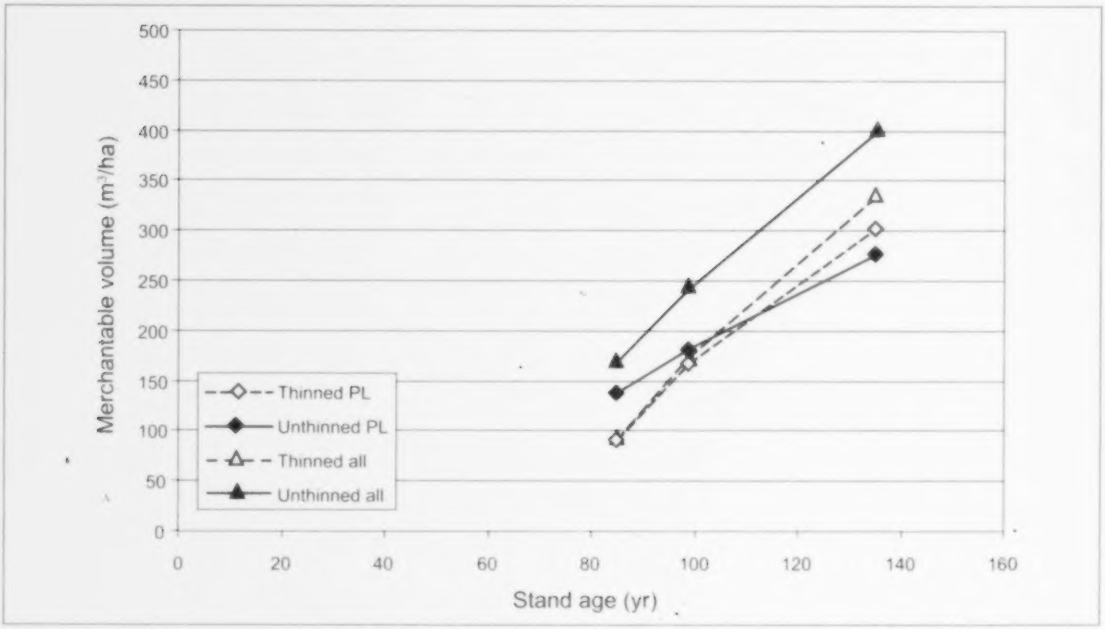

Figure 9. **Merchantable volume (13/7 standard) development after thinning in 1941 (at stand age of 77 years) at the K-57 site.** PL = lodgepole pine.

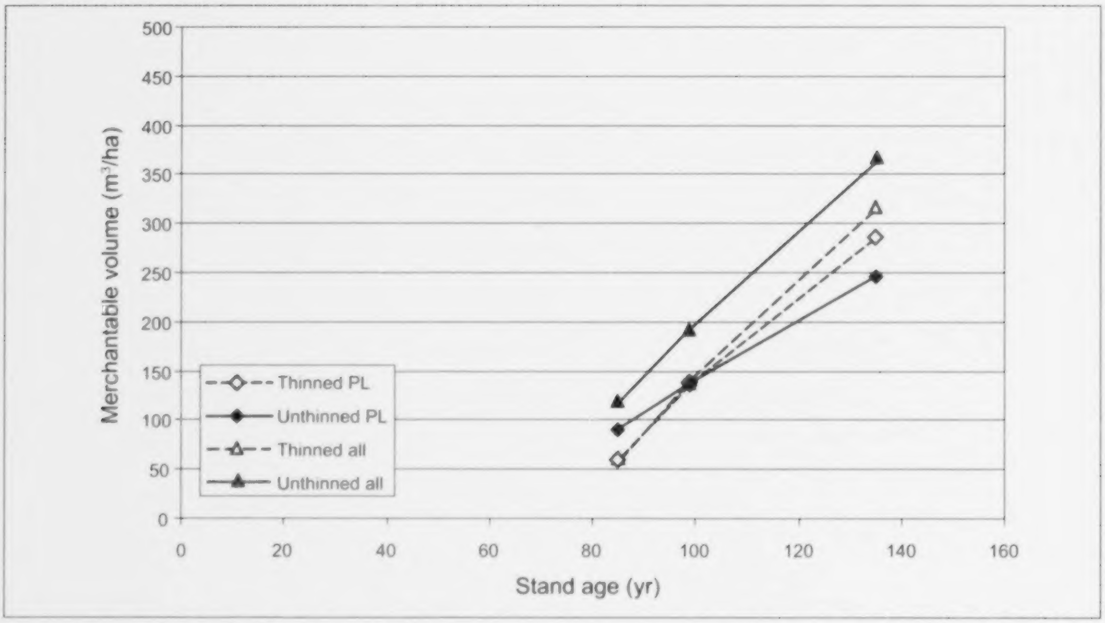

Figure 10. **Merchantable volume (15/10 standard) development after thinning in 1941 (at stand age of 77 years) at the K-57 site.** PL = lodgepole pine.

MacKay Thinning Experiment, Project A-34 (1954)

Location and Access

To access the MacKay site (53°32.7'N, 115°32.3'W, legal location SW¼-3-53-11-W5), travel west on Highway 16 from Edmonton, and follow these directions:

Turn left (south) on Range Road 113 and travel 4.9 km.

Turn right (south) just after the curve, at the sign reading "Penn West 02-18-52-11 W5M" and travel 2.7 km.

Watch for blue boundary paint and site signage on the right.

Establishment and Objectives

The MacKay thinning experiment was established in 1954 by L.A. Smithers, of the Department of Northern Affairs and National Resources, Forestry Branch, in a 22-year-old fire-origin lodgepole pine stand. The objective of the experiment was to determine whether precommercial thinning of lodgepole pine can improve merchantable volume and quality at a young age and in turn shorten rotation and increase annual allowable cuts. Second-entry thinnings were originally planned for two of the five treatments but were carried out in only one. The thinning treatments were applied as prescribed spacings to yield a set stand density. Control plots were left unthinned. Three previous publications have reported results from this experiment (Smithers 1957; Holmes 1961; Johnstone 1981b).

Site Description

The MacKay experiment site is in the Lower Foothills subregion of west-central Alberta. The soils are Brunisolic Grey Luvisols developed on a flat, gently sloping (<5% grade) site. Surface soils are mostly silt loam fluvioeolian veneers overlying clay tills (blocks A and B) and sandy loam over sandy clay (block C) (Johnstone 1981b). Some gleying has been observed in these soils, and high water tables occur in local topographic low spots (Ecotope Consulting Services 1999). The ecological moisture regime is mesic, and the ecological nutrient regime is poor (Ecotope Consulting Services 1999). This site was classified in 2003 as having the following range of plant community types: C1.1 lodgepole pine/Canada buffalo-berry/hairy wild rye (plot B4), D1.1 lodgepole pine-black spruce/Labrador tea/feather moss (plots A1–A5, B1–B3, B5, C1–C5), D1.3 lodgepole pine-black spruce/feather moss (plots A6, B6, C6), and E1.1 lodgepole pine/green alder (plot D1).

Experimental Design and Treatments

The experiment consisted of three blocks of similar productivity, each approximately 1.5 ha in size. Block A was initially less dense (7300 stems per hectare) than blocks B (11 000 stems per hectare) and C (10 500 stems per hectare) (Johnstone 1981b). The experimental design was a randomized complete block, with an unthinned control and five thinning treatments in each block:

Prescription	Post-treatment density
1.52-m spacing	3700 stems per hectare (1 plot)
1.83-m spacing	2600 stems per hectare (3 plots)
2.44-m spacing	1500 stems per hectare (1 plot)

Three plots in each block were thinned to 2600 stems per hectare. Two of these were left at that density, and one was rethinned to 70% of its basal area in 1969 (2600CT treatment). Rethinning to 50% of basal area was intended for a second plot, but this treatment was never carried out, which left two plots at 2600 stems per hectare in each block. An unreplicated treatment of 750 stems per hectare (3.66-m spacing; block D) was also established just south of block C.

Felling was done by hand, and slash was left on the blocks. A spacing grid was set up as a guideline; however, more effort was made to retain the most vigorous trees (according to height growth) than to rigidly adhere to the spacing prescription.

A measurement plot was established in the center of each treatment plot, 0.08 ha in blocks A, B, and C, and 0.30 ha in block D. All living trees in each measurement plot were tagged and measured for diameter at breast height in 1954, 1960, 1969, 1979, 1989, 1996, and 2003. In 1954, at least 30 "height trees" were selected in each plot to represent the full range of diameters present, and these trees were measured at each subsequent measurement date. Only tagged trees were measured until 1979, at which point any additional trees that had reached breast height in the control plots were tagged and subsequently measured. In 2003, all live trees were measured for height, height to live crown, and crown radius.

Results after 49 Years

Tree Growth and Mortality

Mortality of the residual trees was very low in all treatments, with annual mortality less than 1% over the 49-year measurement period (Fig. 11). Mortality in the 2600CT treatment included the trees removed in the second thinning. Comparison with results for the treatments with 2600 and 3700 stems per hectare indicated that the second thinning in the 2600CT treatment captured most of the mortality that would have occurred had the second thinning not taken place. Although there was some variation over the measurement period, cumulative mortality increased with increasing stand density in the various treatments.

Initial average diameter was greater as stand density decreased, because of the "chainsaw effect" (Fig. 12). The highest rate of increase in diameter growth was for the treatment with 750 stems per hectare. Initial average diameter was greater (and increased more quickly) for all of the thinned treatments than for the control. However, by the 2003 measurement, average diameter for all of the thinned plots, except those with 750 stems per hectare, was within a 2-cm range, and was only 2 to 3 cm greater than in the unthinned control plots. The 2600CT treatment, which was rethinned in 1969, had the same diameter growth at the beginning of the study period as the treatment with 1500 stems per hectare; later on, diameter growth for the 2600CT treatment slightly exceeded that for the latter.

Height growth was similar in most of the plots, with trees in the 750 stems per hectare treatment growing taller than trees in the other treatments and the control trees being shortest (Fig. 13). Height growth showed a consistent rate of increase in the treatments with 750, 2600, and 3700 stems per hectare and in the control plots. The 2600CT treatment had the greatest initial rate of height growth but a lower rate over the last few measurements. By 2003, average height in the treatment with 750 stems per hectare was approximately 1 m greater than in the treatment with the next tallest trees (2600CT) and almost 5 m taller than the control.

Stand Development

The thinned treatments all showed a slight, gradual decline in stand density until 1996 and a slight increase between 1996 and 2005 (Fig. 14). This increase was due to tagging and recording of ingrowth understory trees in 2003; however, ingrowth was probably more gradual than the data indicate, because new ingrowth trees were not tagged and recorded except in 1979 and 2003. The large increase in density in the control plots in 1979 was due to tagging and recording of ingrowth trees that had formerly been ignored. Interestingly, stand density development for the 2600CT treatment followed the same pattern as that for the 2600 treatment until rethinning in 1969, after which it followed the same pattern as the 1500 treatment. The 2600CT treatment had the greatest rate of increase in stand density after 1996, and stand density continued to increase until it was equal to that of the 2600 treatment.

Diameter distribution curves were ordered consistently with respect to stand density, with smaller diameter associated with denser treatments, although there was a great deal of overlap (Fig. 15). The narrowest distributions (least variability) occurred in the 2600CT and control plots. The 2600CT results were not surprising, given that the rethinning removed most of the smallest trees; however, the control plots had been expected to contain a broader range of diameters. Thinning had little impact on height–diameter relationships (Fig. 16).

Total basal area was greatest in the control plots, which also had the greatest rate of increase in basal area up to and including the latest measurement (in 2003), when basal area peaked at 49.5 m^2/ha (Fig. 17). The rate of basal area increment decreased slightly over the last measurement period for the densest treatment, but otherwise basal area increased steadily throughout the experiment for all thinning treatments. Basal area was higher in plots of higher density, but the relative differences among treatments diminished with time. The basal area of the 2600CT treatment was initially similar to and grew at the same rate as that of the 3700 treatment, until rethinning caused a reduction in basal area. At that point, basal area of the 2600CT treatment was similar to that of the 1500 treatment. However, over the last 14 years of the reporting period, the basal area of the 2600CT treatment increased at a greater rate than that of the 1500 treatment, and at the time of the most recent measurement, its basal area was closer to that of the 2600 treatment.

Total volume had patterns similar to those for basal area, and by 2003, total volumes were consistently greater in plots with higher stand densities (Fig. 18). The exception was the 2600CT treatment, which had higher than expected volume. In 1969, the 2600CT treatment had a greater volume than all other treatments, with approximately 140 m^3/ha. After its second thinning, the total volume dropped, but by the next measurement, the volume was as great as that of the 2600 treatment, which it continued to match for the rest of the measurement period. The differences in total volumes among the plots with stand density of 2600 stems per hectare or higher were less than 20 m^3/ha. Total volume was more than 25 m^3/ha lower in the treatment with 1500 stems per hectare and more than 25 m^3/ha lower again in the treatment with 750 stems per hectare.

Calculated at the 13/7 merchantability standard, volume in the 2600CT treatment was 270 m^3/ha in 2003, greater than that of all the other treatments throughout the experimental period (Fig. 19). The control plots had the lowest 13/7 merchantable volumes, which reached only 191 m^3/ha in 2003. Other than the control, the 2600 and 3700 treatments had the lowest initial 13/7 volumes in 1969, but by 2003 both of these treatments had over 260 m^3/ha, second only to the 2600CT treatment.

Merchantable volumes calculated at the 15/10 merchantability standard followed similar patterns to those for the 13/7 standard, although the volumes were slightly smaller (Fig. 20). The volume curves for the treatments with 2600 and 3700 stems per hectare matched but did not surpass the curves for the treatments with 750 and 1500 stems per hectare by 2003.

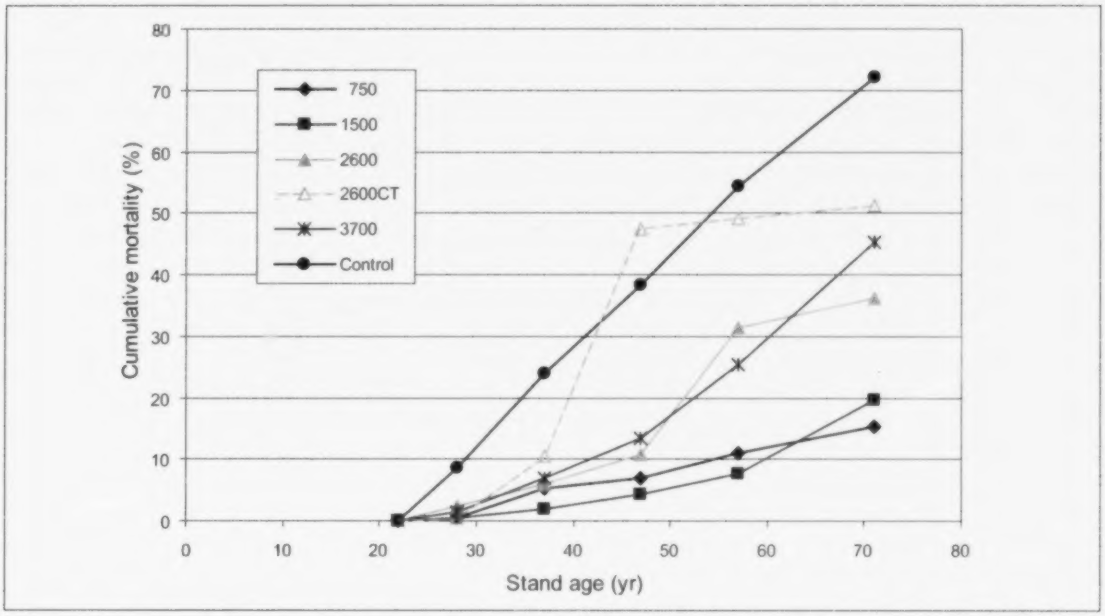

Figure 11. **Cumulative mortality after thinning in 1954 (at stand age of 22 years) at the MacKay site.** Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969.

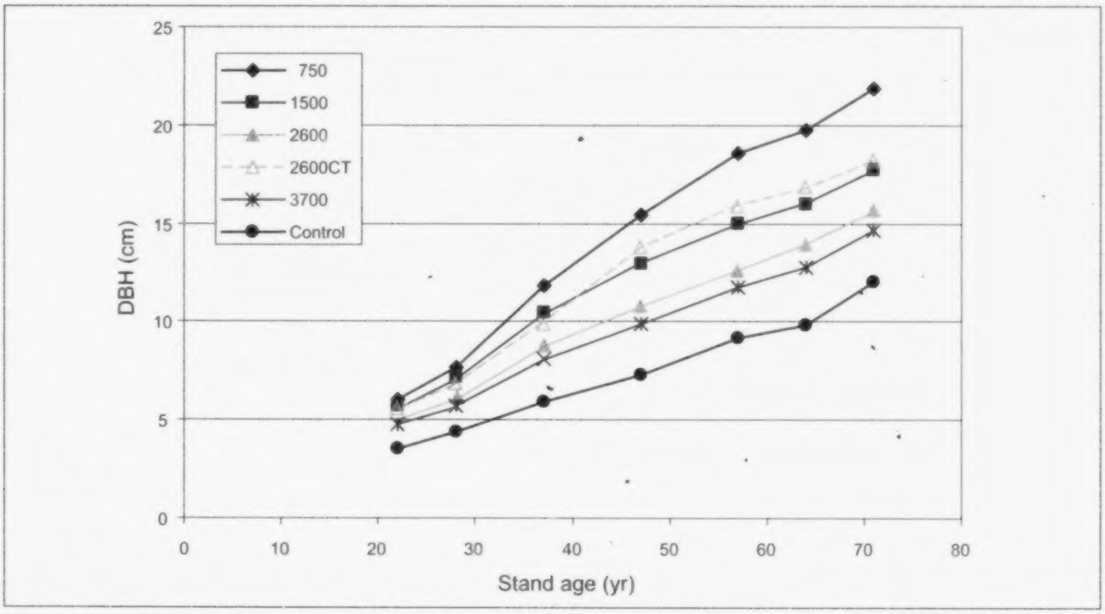

Figure 12. **Diameter growth after thinning in 1954 (at stand age of 22 years) at the MacKay site.** Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969. DBH = diameter at breast height.

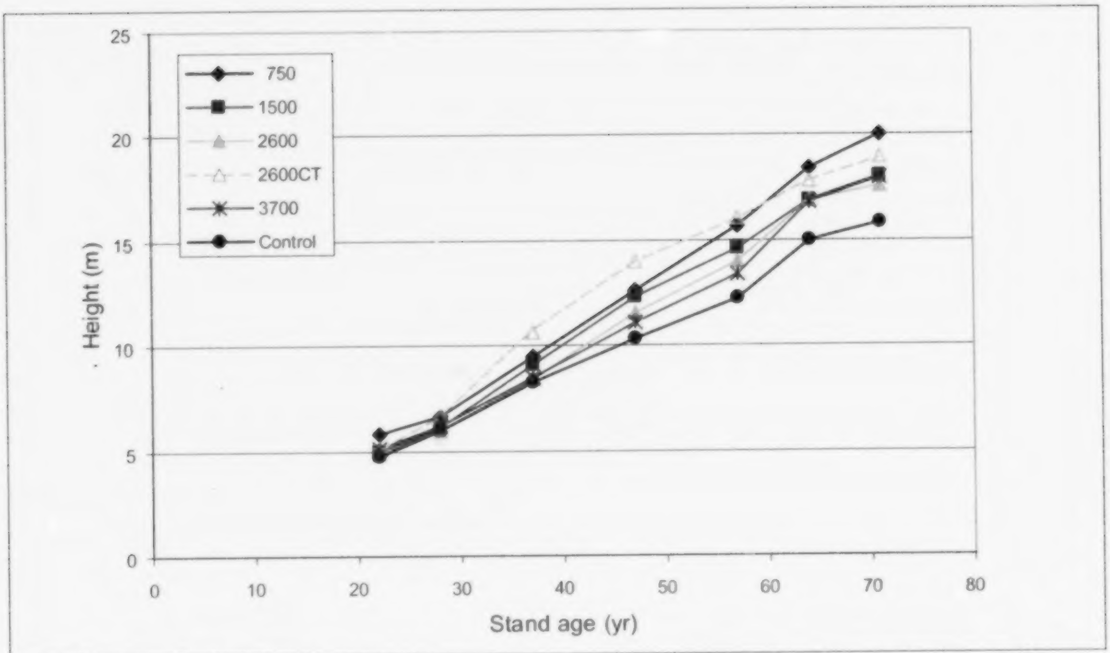

Figure 13. **Height growth after thinning in 1954 (at stand age of 22 years) at the MacKay site.** Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969.

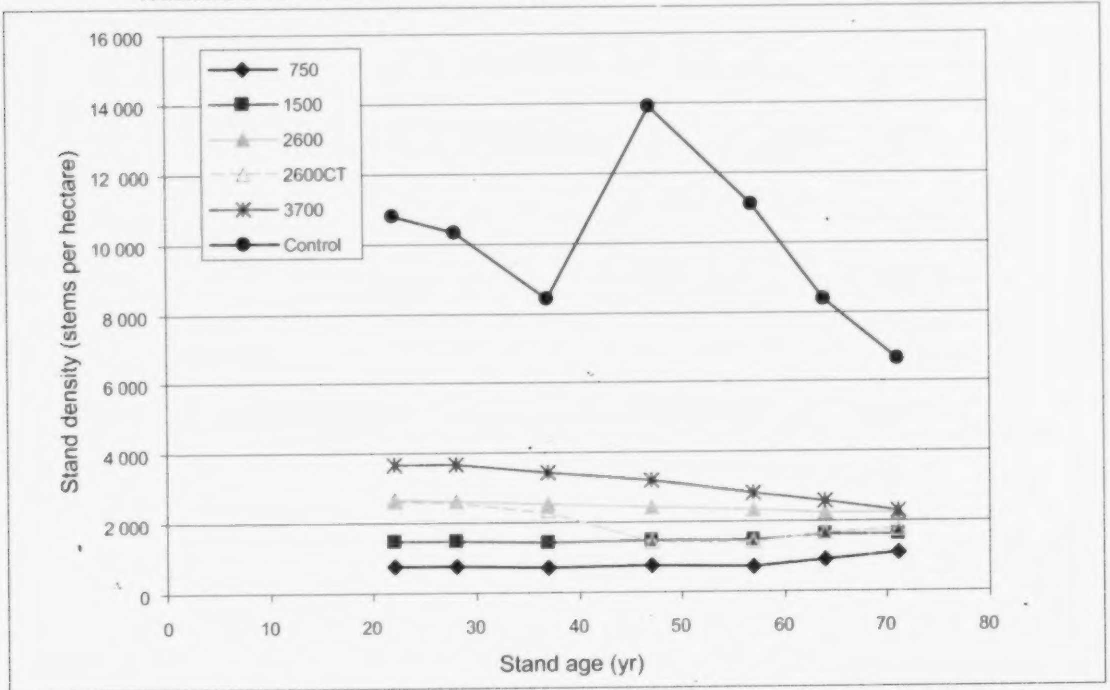

Figure 14. **Stand density development after thinning in 1954 (at stand age of 22 years) at the MacKay site.** Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969.

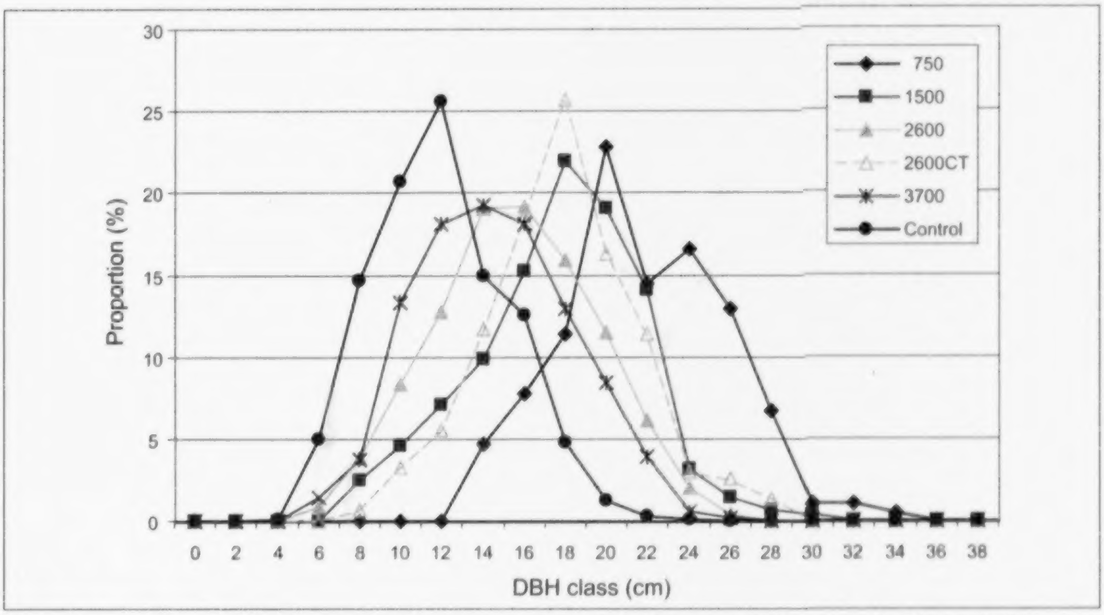

Figure 15. **Diameter distribution, by treatment, 49 years after thinning in 1954 at the MacKay site.** Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969. DBH = diameter at breast height.

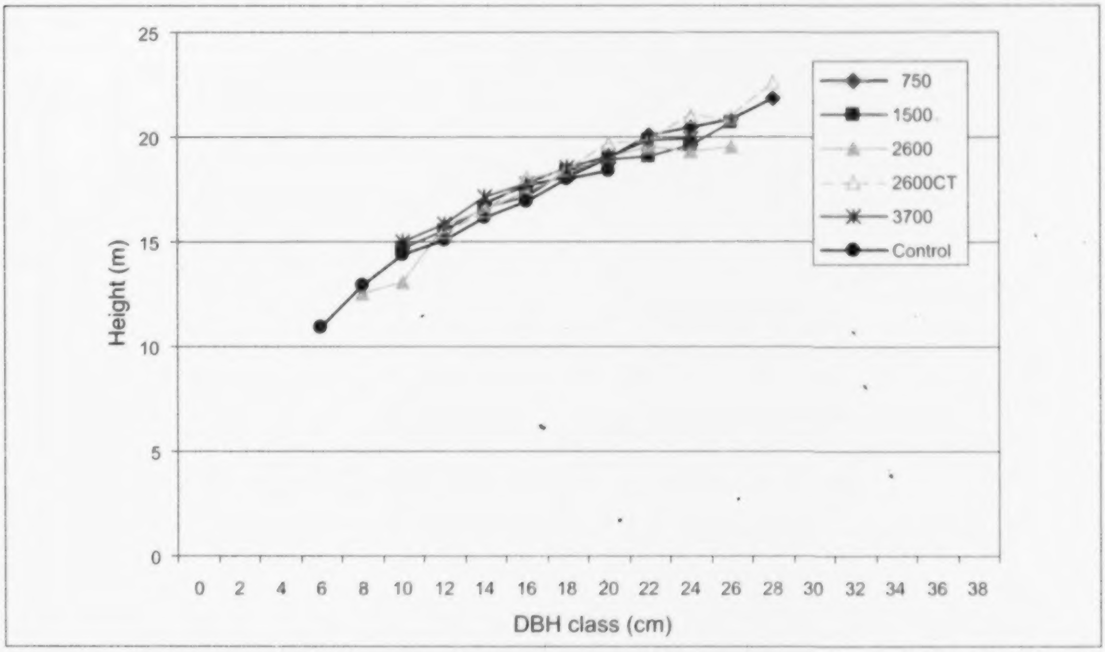

Figure 16. **Height–diameter relationships, by treatment, 49 years after thinning in 1954 at the MacKay site.** Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969. DBH = diameter at breast height.

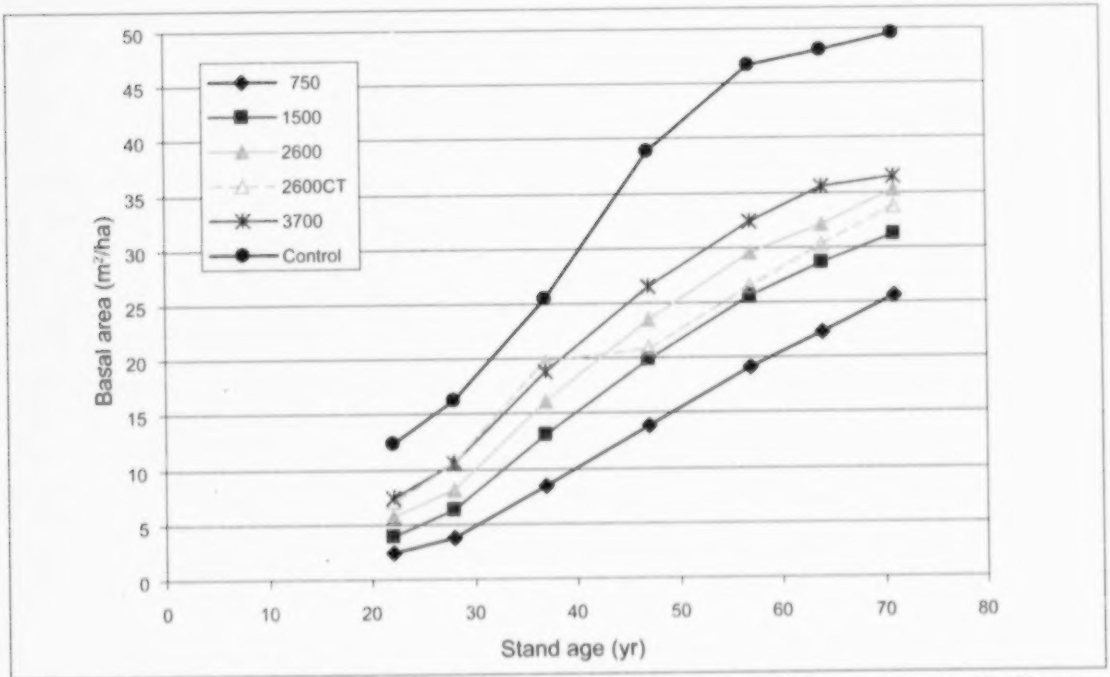

Figure 17. **Basal area development after thinning in 1954 (at stand age of 22 years) at the MacKay site.** Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969.

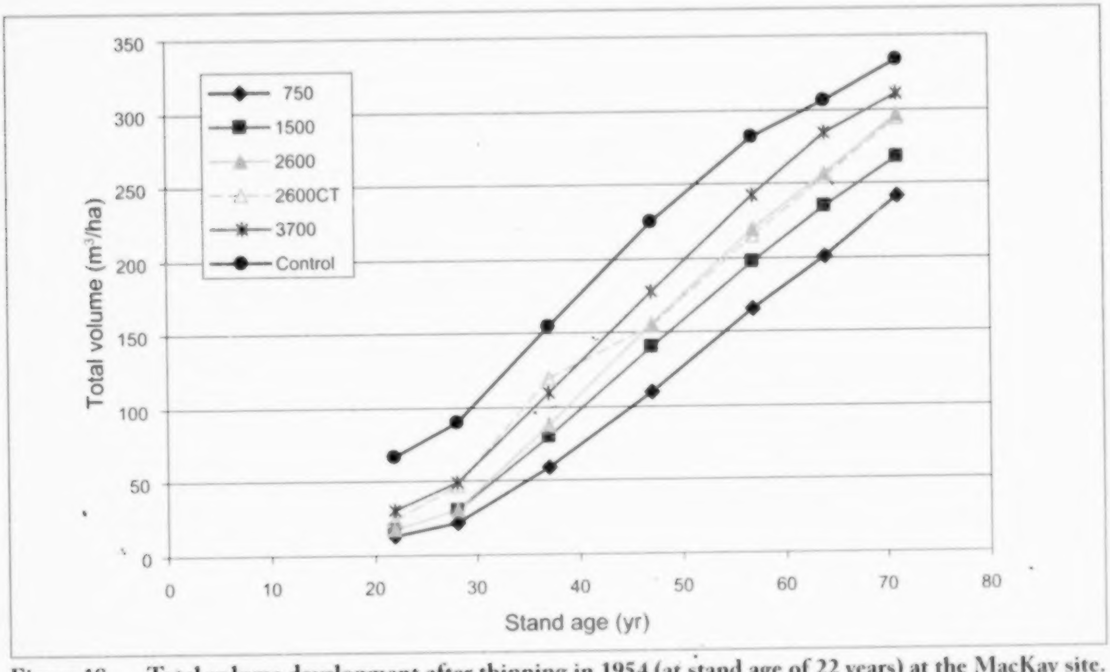

Figure 18. **Total volume development after thinning in 1954 (at stand age of 22 years) at the MacKay site.** Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969.

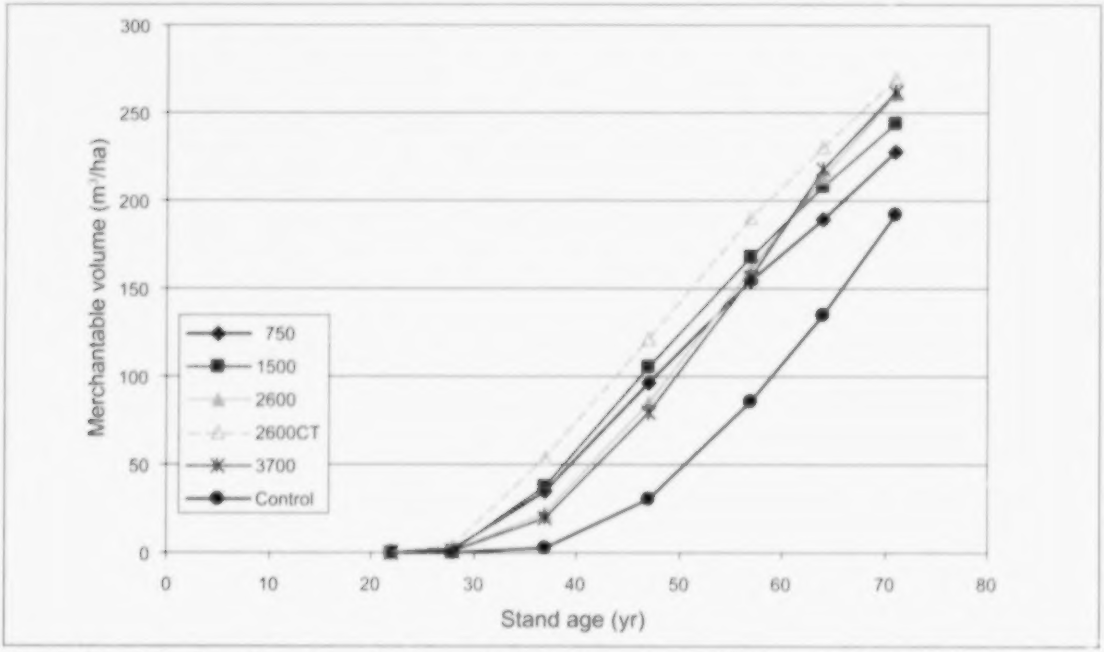

Figure 19. Merchantable volume (13/7 standard) development after thinning in 1954 (at stand age of 22 years) at the MacKay site. Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969.

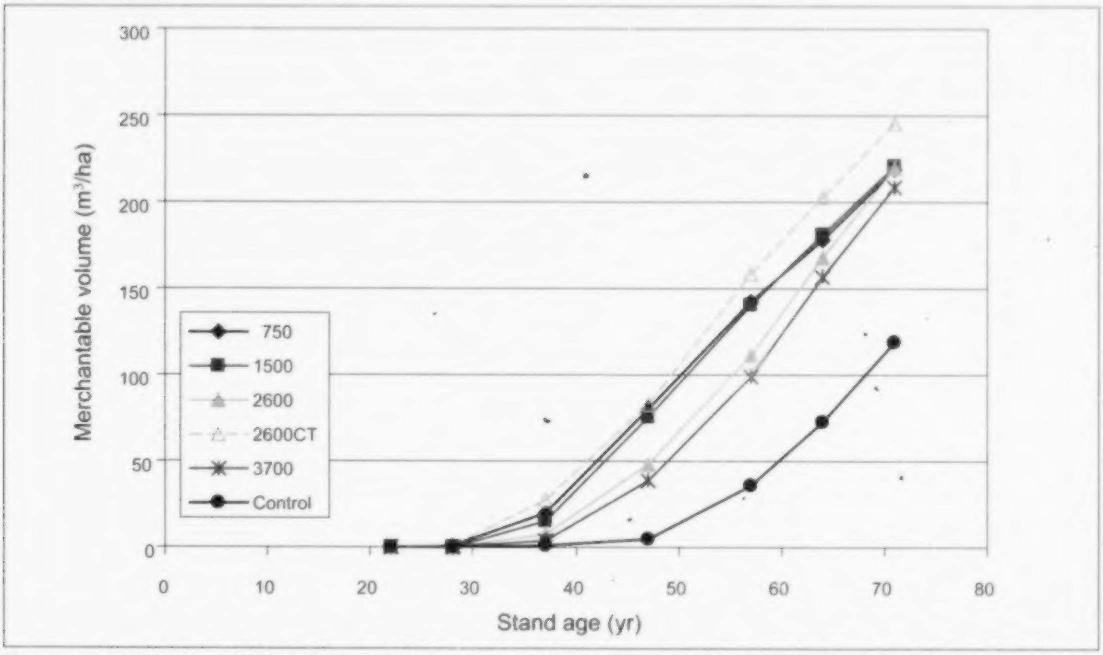

Figure 20. Merchantable volume (15/10 standard) development after thinning in 1954 (at stand age of 22 years) at the MacKay site. Treatments are designated by stand density after thinning (stems per hectare); 2600CT = treatment that was rethinned to 70% of its basal area in 1969.

Strachan Thinning Trial (1951)

Location and Access

The Strachan trial site (52°15.4'N, 115°8.0'W, legal location 7-38-8-W5) is located within the Des Crossley Demonstration Forest, 20 km southwest of Rocky Mountain House. To access the Strachan trial site from Rocky Mountain House, follow these directions:

Travel west from Rocky Mountain House on Highway 11A to the junction with Highway 752.

Travel 24.6 km south and west on Highway 752 to the junction with Range Road 85A.

Travel 0.4 km south on Range Road 85A, then turn right (west) into the parking lot for the Des Crossley Demonstration Forest.

Establishment and Objectives

The Strachan thinning plots were established in a mature pine stand in 1951 by D.I. Crossley of the Department of Resources and Development, Forestry Branch, as part of a program of lodgepole pine studies in the Strachan Experimental Block, a quarter-section set aside by the Alberta Forest Service for silviculture research. The stand originated after an 1866 fire. The objective of the overall program was to determine suitable silvicultural practices for thinning, harvesting, and regenerating lodgepole pine. Three improvement cut treatments were established: heavy low thinning, heavy crown thinning, and sanitation cutting. An uncut control plot and a number of different harvest and conversion cuts were also established. The objective of the thinning treatments was to determine tree growth and stand yield responses. The only previous publication from this trial was a note describing its establishment (Crossley 1955).

Site Description

The Strachan trial site is in the Lower Foothills ecological subregion of southwestern Alberta, located on a gently undulating plain of shallow alluvium over uniformly stratified outwash (Crossley 1955). Drainage is moderately rapid; the ecological moisture regime is submesic, and the nutrient regime is poor to medium. The site was classified in 2005 as having a C1.2 lodgepole pine/bog cranberry plant community.

Experimental Design and Treatments

The Strachan thinning trial was composed of four treatment blocks of 4.05 ha each. Treatments were not replicated. Cutting was done by hand-falling and horse-skidding and took place from the summer of 1951 into the winter of 1952. The low thinning and crown thinning treatments were intended to leave about 740 well-spaced stems per hectare by thinning from below and from above, respectively. This required the removal of about half of the stems and 40% of the basal area. The sanitation cut did not consider final density or spacing; instead, trees with a diameter at breast height of over 7.6 cm that were badly suppressed, diseased, or deformed, such that they would be unmerchantable as poles or pilings at final harvest, were all removed. The control block was left untouched.

Five measurement plots (1/5 acre; 809.4 m^2) were established in a regular pattern in each treatment block. Total height and diameter at breast height were measured before and immediately after thinning in 1951 and again in 1962; however, only data summaries are available from these measurements. Tree-level data are available from 2005, when all live trees were measured for diameter, height, height to live crown, and crown radius. Measurements taken in 1996 have unresolved problems and are not presented.

Results after 54 Years

Tree Growth and Mortality

Mortality of crop trees in the first 5 years after treatment ranged from about 5% in the low thinning treatment to about 13% in the unthinned control (Fig. 21). In the next 6 years, the rate of mortality declined slightly, resulting in about 21% cumulative mortality for the control block, 18% for the crown thinning block, and 16% for the sanitation cut block; the low thinning block continued to experience the least mortality, at 9%. By stand age 139 years, mortality in the control block had risen to about double that in the thinning treatments. The crown thinning treatment still had greater mortality (28%) than the sanitation cut treatment (24%); however, the rate of mortality had decreased for both treatments. Mortality in the low thinning treatment continued at about the same rate as in the earlier periods, and by 139 years this treatment had lost more trees (32%) than either of the other cutting treatments.

Initially, the average diameter in the low thinning treatment was approximately 2 cm greater than in the control and the other two treatments, a result of removing smaller trees (Fig. 22). Diameter growth in the control plots was greater than in the three thinning treatments. Although trees in the control block had almost the lowest average diameter in 1951 (15.8 cm), by 2005 they had caught up with the low thinning treatment, at about 23 cm average diameter. The diameters for the sanitation cut and crown thinning treatments were more than 2 cm less than the average diameters for the other two treatments.

At stand age 139 years, 54 years after treatment, the control plots had the greatest average crop tree height (21.0 m), followed by the low thinning treatment (19.8 m), the sanitation cut (17.9 m), and the crown thinning treatment (17.0 m). No earlier height data are available.

Stand Development

In 1951, stand density in the control plots was twice that in the crown thinning and low thinning plots; however, by 2005 rapid self-thinning in the control plots had decreased stand density to the same levels as observed in the thinned treatments (Fig. 23). The three cutting treatments all had episodes of net density increase due to ingrowth and episodes of decline, when mortality was the dominant factor. In the low thinning treatment, ingrowth peaked soon after thinning, whereas in the sanitation cut and crown thinning plots, ingrowth became important in the later years of the measurement period.

Diameter distributions reflected these density trends, clearly showing the smallest cohort of small-diameter ingrowth trees for the control plots, slightly more for the low thinning treatment (where ingrowth occurred earlier), and the most small ingrowth trees in the crown thinning treatment and sanitation cut (Fig. 24). The range of diameters was very similar among the treatments, but the modal diameter was significantly lower for the control block. The height–diameter relationships in the various treatments were similar; the only difference appeared to be greater height (by about 1 m) for a given diameter in the control block (Fig. 25).

The control plots maintained the greatest basal area throughout the study until 2005, when basal area increase was limited because of mortality, which resulted in a value slightly less than that of the sanitation cut (Fig. 26). Basal area for the sanitation cut rose most quickly, increasing by 17 m^2/ha between 1951 and 2005. During the same period, basal area increased by 13 m^2/ha in both the low thinning and crown thinning blocks and by only 4 m^2/ha in the control plots. Total volume followed the same trends as basal area, except that volume in the control plots remained just above that in the sanitation cut block (Fig. 27). Merchantable volumes in 2005 exhibited the same trends and relative values as total volumes, because of the large diameter of trees in these old stands (Fig. 28).

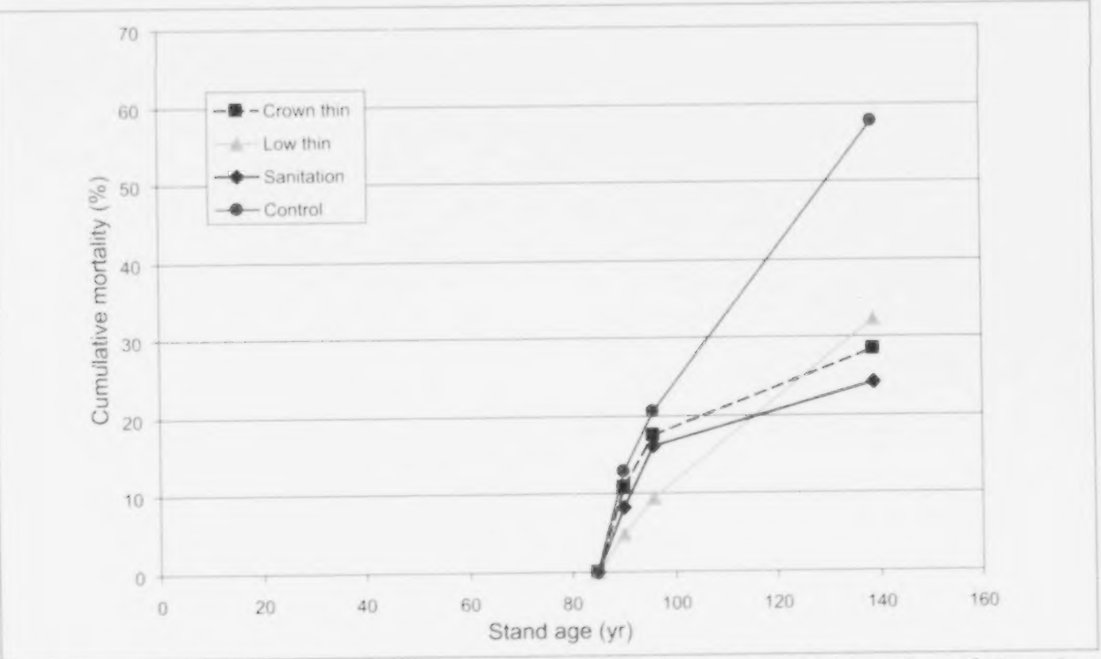

Figure 21. **Cumulative mortality between 1956 and 2005, after thinning in 1951 (at stand age of 85 years), at the Strachan site.**

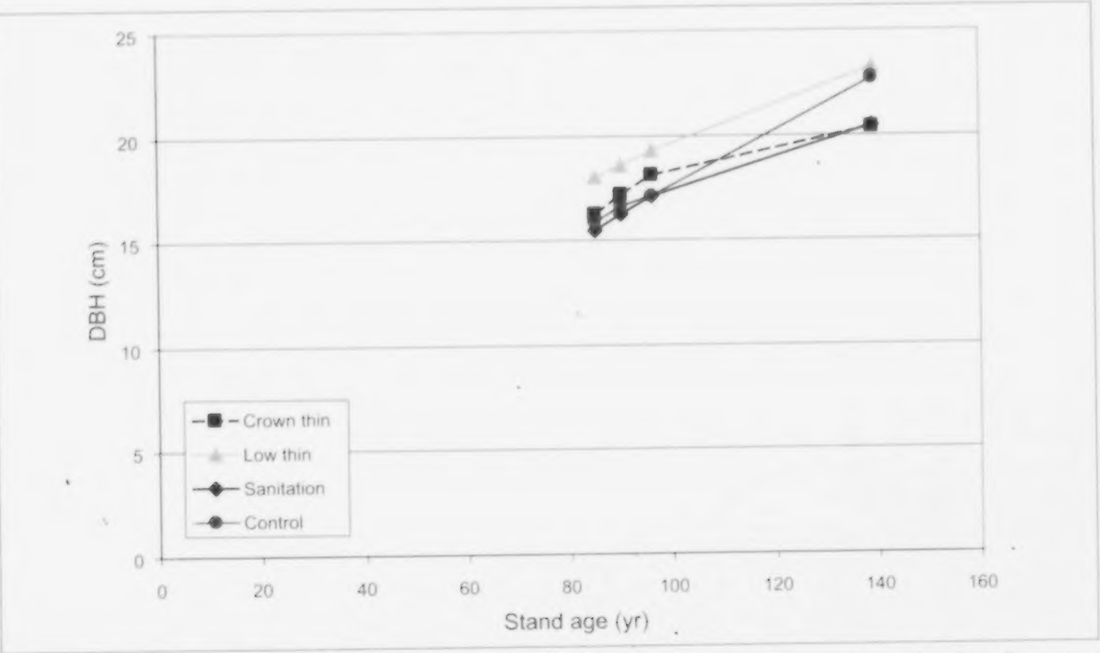

Figure 22. **Diameter growth after thinning in 1951 (at stand age of 85 years) at the Strachan site.** DBH = diameter at breast height.

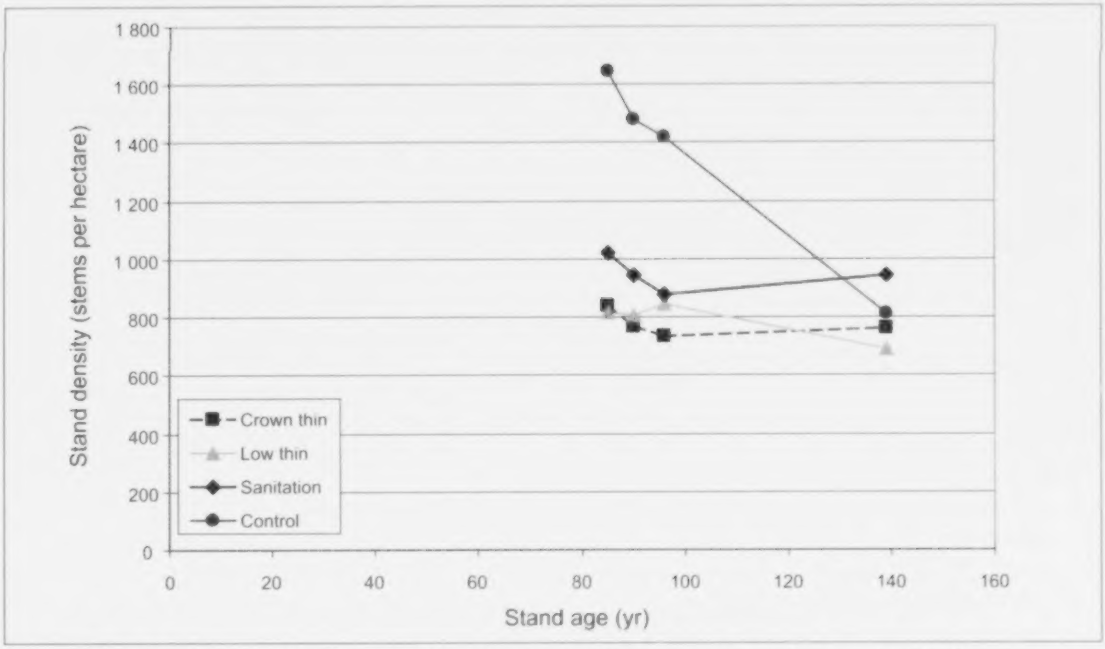

Figure 23. Stand density development after thinning in 1951 (at stand age of 85 years) at the Strachan site.

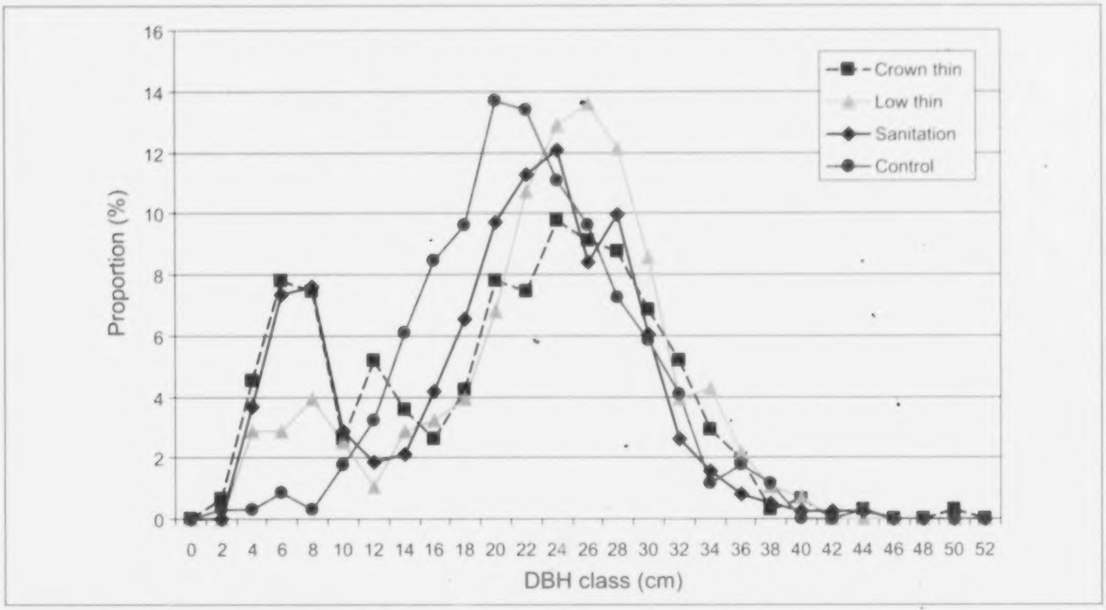

Figure 24. Diameter distribution, by treatment, 54 years after thinning in 1951 at the Strachan site. DBH = diameter at breast height.

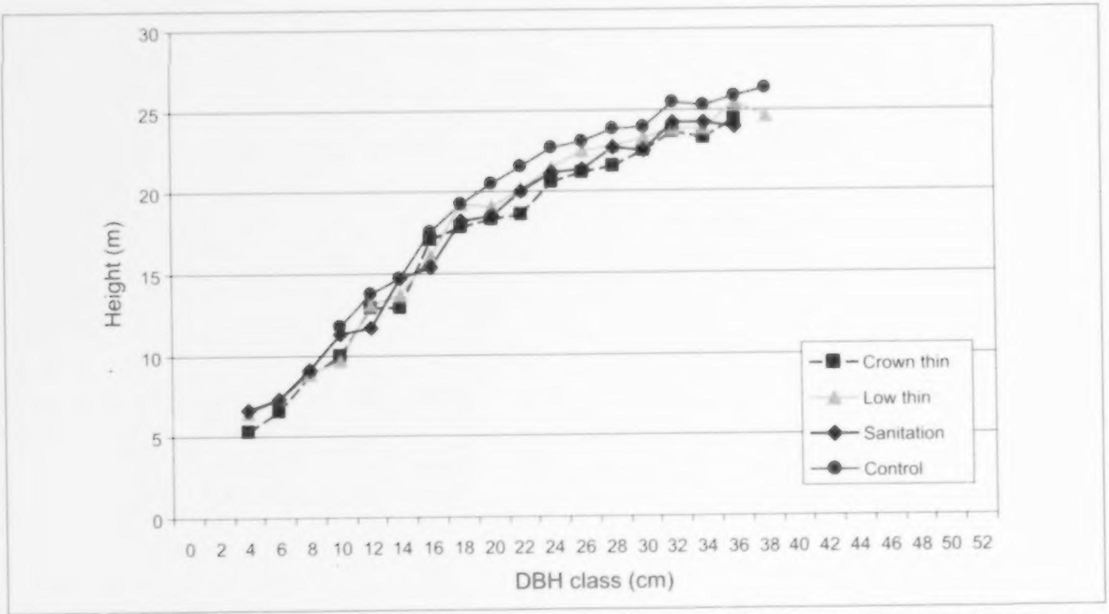

Figure 25. **Height–diameter relationships, by treatment, 54 years after thinning in 1951 at the Strachan site.** DBH = diameter at breast height.

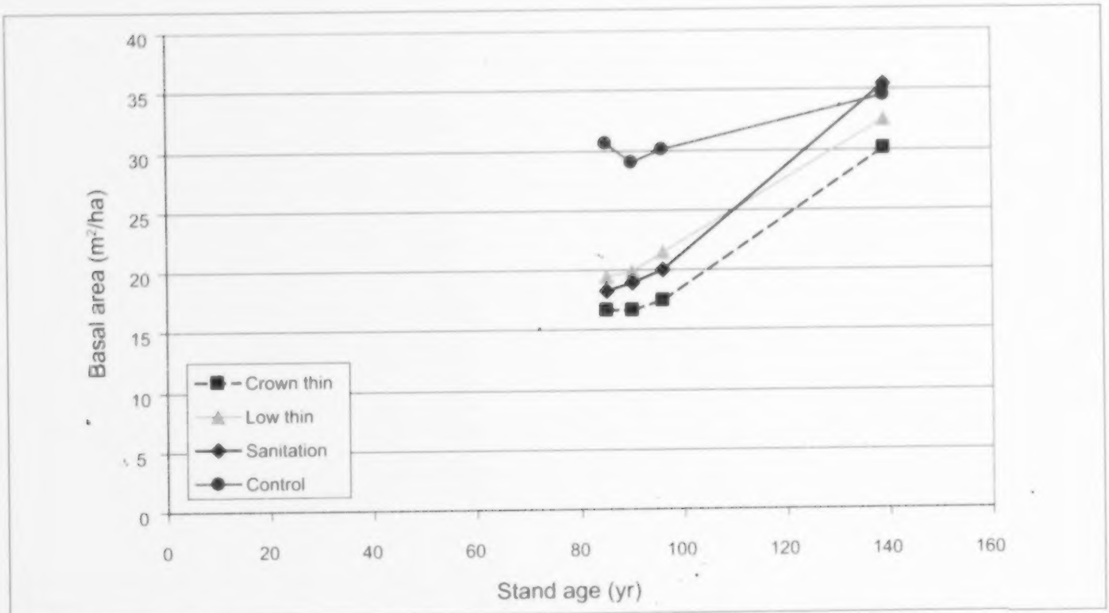

Figure 26. **Basal area development after thinning in 1951 (at stand age of 85 years) at the Strachan site.**

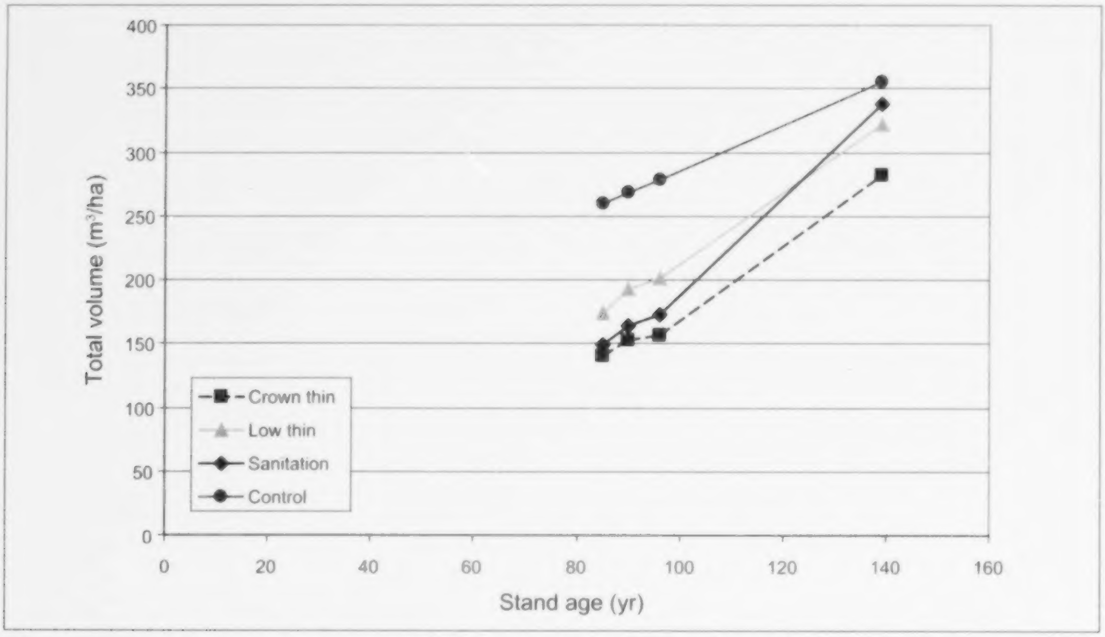

Figure 27. Total volume development after thinning in 1951 (at stand age of 85 years) at the Strachan site.

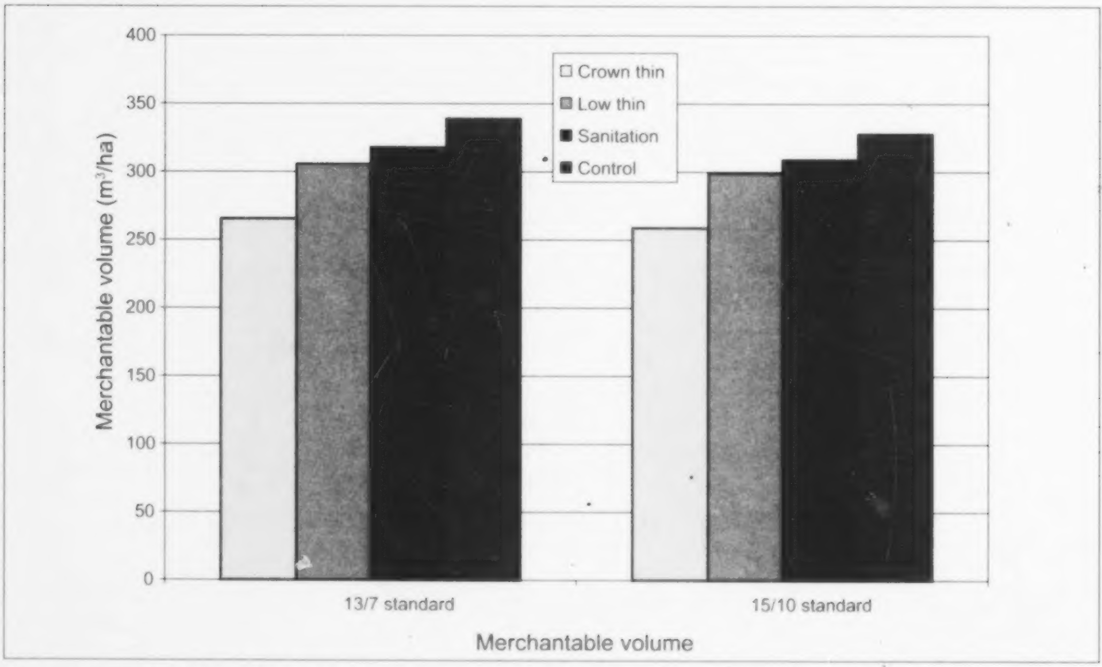

Figure 28. Merchantable volume for two merchantability standards at stand age of 139 years, 54 years after thinning, at the Strachan site.

Swan Lake Thinning Experiment (1976)

Location and Access

The Swan Lake experiment site (52°4.7'N, 115°10.1'W, legal location 12-36-9-W5) is located 37 km southwest of Rocky Mountain House. To access the site, follow these directions from Caroline:

Travel 8 km west on Highway 22 to Highway 591.

Travel 23 km west on Highway 591 to the Swan Lake Recreation Area Road.

Turn right on the Swan Lake Recreation Area Road, and travel 1.7 km to the sign reading "Prime West Energy, Ricinus Cardium, Unit #2."

Turn right at the sign, and travel 1.6 km to a fork in the road.

Keep left at the fork, then travel 4.4 km, to the sign reading "BP Canada Energy, LSD 07-02-36-09 W5M."

Turn left and travel 1.4 km along the BP road.

Watch for blue boundary paint and signage on the right.

Establishment and Objectives

The Swan Lake thinning experiment was established in 1976 in a 9-year-old, fire-origin lodgepole pine stand by I.E. Bella of the Canadian Forestry Service in cooperation with the Alberta Forest Service. The objective of the experiment was to find inexpensive yet effective ways to reduce density and accelerate individual tree growth and thus to increase timber production. Three scarification tools were used to effect the thinning. A paper by Bella (1990) is the only previous publication reporting on this experiment.

Site Description

The Swan Lake experiment site is in the Lower Foothills ecological subregion of southwestern Alberta, located on an area of level to gently undulating topography. It was considered to be uniform and of above-average productivity for lodgepole pine (Bella 1990). The moisture regime is mesic to subhygric, and the nutrient regime is medium. This site was classified in 2003 as having a D1.2 lodgepole pine/green alder plant community.

Experimental Design and Treatments

The Swan Lake thinning experiment had a semirandomized design with two treatment factors: type of scarification implement used and number of passes over the treatment plot. There are two replicates of each treatment combination, and three replicates of untreated controls. Treatment plots were approximately 0.5 ha and control plots about half that size. Three implements were used: shark-fin barrels, Rome disks, and anchor chains. These tools were dragged behind a Caterpillar D8H crawler tractor in either one or two directions in the winter of 1977. The control plots were left untouched. Measurement plots were established in the middle of each treatment plot and were sized to include at least 25 live trees. The size of measurement plots varied from 140 to 196 m^2 for treatment plots and was 12 m^2 for control plots. In 2003, the control measurement plots were enlarged to 100 m^2.

Measurements of diameter at breast height and height were taken in 1977, 1983, 1988, 1994, and 2003. The height of all live trees was measured, and diameter at breast height was measured for all trees above 1.3 m. In 2005, diameter at breast height, total height, height to live crown, and crown radius were measured for all live trees.

Results after 26 Years

Tree Growth and Mortality

Mortality for crop trees (those remaining after thinning and tagged in 1977) over the 26-year measurement period ranged from a low of 40% for the two-way disk treatment to a high of 62% for the two-way chain treatment (Fig. 29). The two-way treatments had greater mortality than one-way treatments when barrels or chains were used, but less mortality when disks were used. The control plots had mortality similar to that of the one-way barrel and chain treatment plots.

Diameter growth was greater in the thinned plots than in the control plots (Fig. 30). Diameter growth in the treated plots was rapid during the first 10 years but slowed after that. By 2003, average diameter for the three two-way treatments and the one-way disk treatment appeared to be converging on similar values, ranging from 12.0 to 13.3 cm. The one-way barrel and chain treatments appeared to yield slower diameter growth rates than the other treatments over the last 15 years of the measurement period, which resulted in diameters about 2 cm smaller in 2005. The unthinned controls have had slower diameter growth from the beginning, producing trees with much smaller diameter (average 7.3 cm in 2005).

With the exception of the two-way disk treatment, height growth was similar for all treatments until 1994 (Fig. 31). Over the next 9 years, trees in the control and one-way chain treatment plots had slower height growth, and by 2003 were about 0.7 to 1.2 m smaller than trees in the other treatments. The two-way disk treatment had the tallest trees, over 12 m in 2003.

Stand Development

Stand densities for all treatments, but not the control, remained low and exhibited only a slow decline over the first 17 years, after which new ingrowth trees were measured (Fig. 32). This led to the rapid rise in stem densities recorded in 2003, when stand density for the one-way barrel treatment increased by over 6000 stems per hectare. Both the one-way and two-way disk treatments had the least ingrowth, with an increase in stand density of about 3000 stems per hectare. The control plots showed a different trend; their stand density started at almost 21 000 stems per hectare in 1977 and has declined since then to 10 500 stems per hectare in 2003.

As expected, the diameter distribution of trees in the unthinned control plots was skewed toward smaller diameters than the thinning treatments (Fig. 33). The diameter distributions of the thinning treatments were similar, although average diameters differed as noted above. The modal values for one-way barrel and two-way chain treatments were 2 cm (one diameter class) lower than those for the other treatments and 2 cm greater than those for the controls.

The height–diameter relationships were similar across most treatments (Fig. 34). Control trees tended to be taller for a given diameter, as expected for plots with the greatest density. There was also some suggestion that the trees in the two-way disk treatment plots were more slender, as well as having the greatest average height (as noted above).

Basal area of the control plots increased rapidly for the first 17 years and reached 42.5 m^2/ha by 1994 (Fig. 35). Over the next 9 years, the basal area of the control plots increased by only 1.5 m^2/ha. The treatment plots showed the opposite trend: the basal area increased slowly over the first 17 years, then rapidly for the next 9 years. This effect was likely due to the addition of measurements for ingrowth trees, which increased the overall basal area. Basal area in the one-way barrel treatment plots increased most rapidly, and by 2003 this treatment had a basal area of over 40 m^2/ha, nearly as great as the control. The one-way disk treatment plots had the smallest basal area in 2003, with only 31.4 m^2/ha.

Total volume showed the same pattern as basal area (Fig. 36), but merchantable volumes told a different story (Figs. 37 and 38). All treatments and the control had relatively small increases in merchantable growth (at the 13/7 standard) until 1994 and then considerable growth until 2003 (Fig. 37). The two-way disk treatment had the most rapid growth, with nearly 84 m^3/ha of growth between 1994 and 2003. This was followed closely by the one-way disk and the two-way chain treatments, which by 2003 had reached nearly 79 m^3/ha merchantable volume. The one-way chain treatment had the smallest 13/7 merchantable volume, reaching only 32.5 m^3/ha by 2003, not quite double that of the control, which had reached 18.7 m^3/ha by 2003. Within each of the disk and the chain implement types, the two-way treatment yielded greater merchantable volumes than the one-way treatment.

Merchantable volumes for the 15/10 standard showed similar patterns, with little growth until the 17th year and fastest growth occurring in the disk treatment plots (Fig. 38). Again, trees in the two-way disk treatment plots grew most rapidly, and by 2003 these plots had a 15/10 merchantable volume of 45.3 m^3/ha. The one-way disk treatment also did well, yielding about the same volume as the second-ranked two-way barrel treatment. The other one-way treatments (barrel and chain) had just over 5 m^3/ha more than the control plots, which grew slowest, with a volume of only 4.5 m^3/ha in 2003.

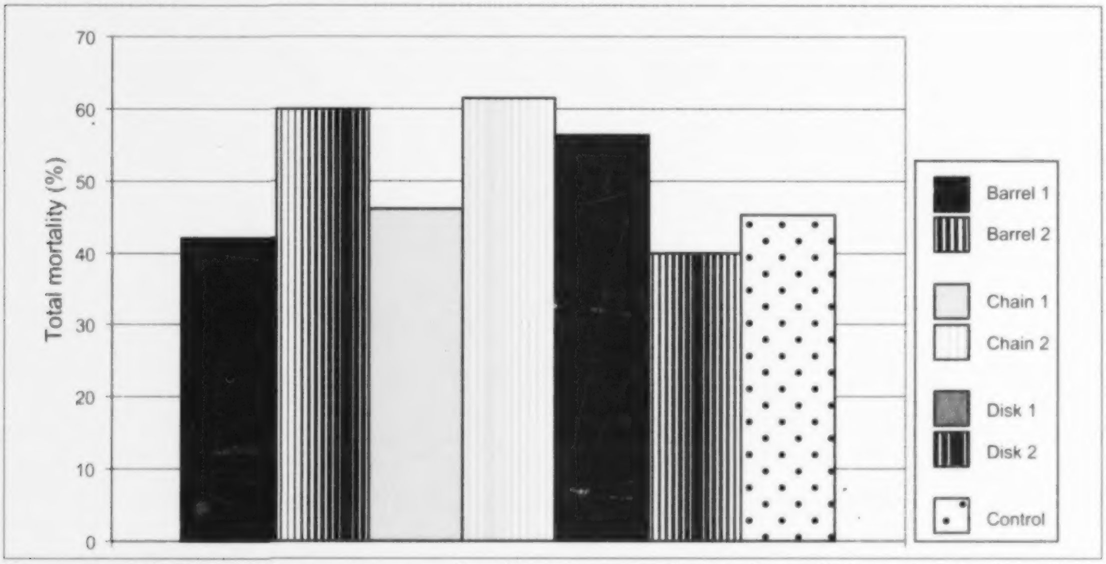

Figure 29. **Total mortality over 26 years after thinning in 1977 (at stand age of 10 years) at the Swan Lake site.**

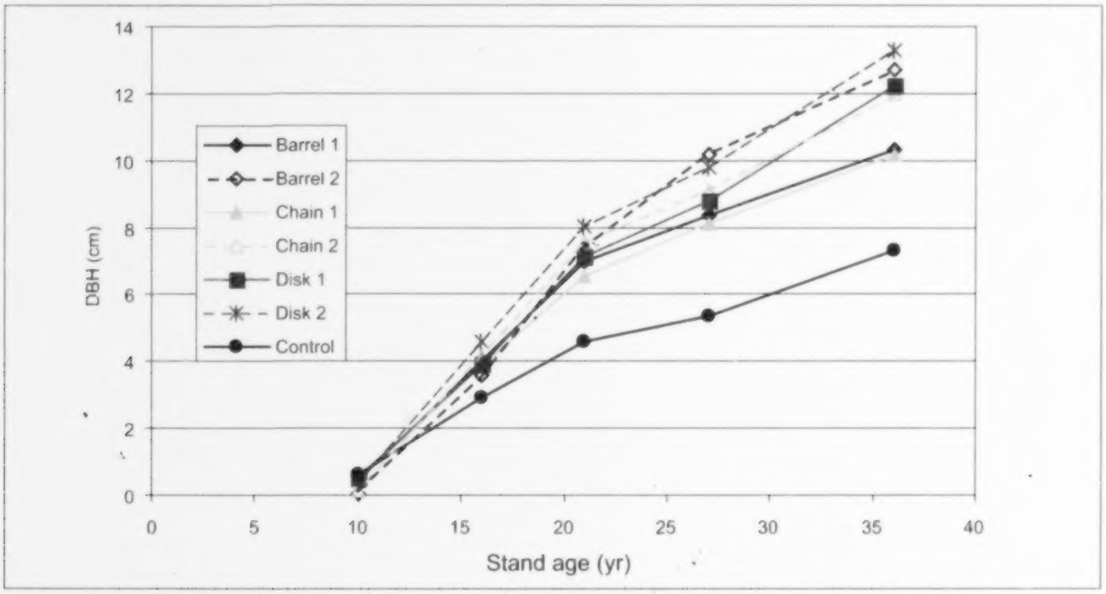

Figure 30. **Diameter growth after thinning in 1977 (at stand age of 10 years) at the Swan Lake site.** DBH = diameter at breast height.

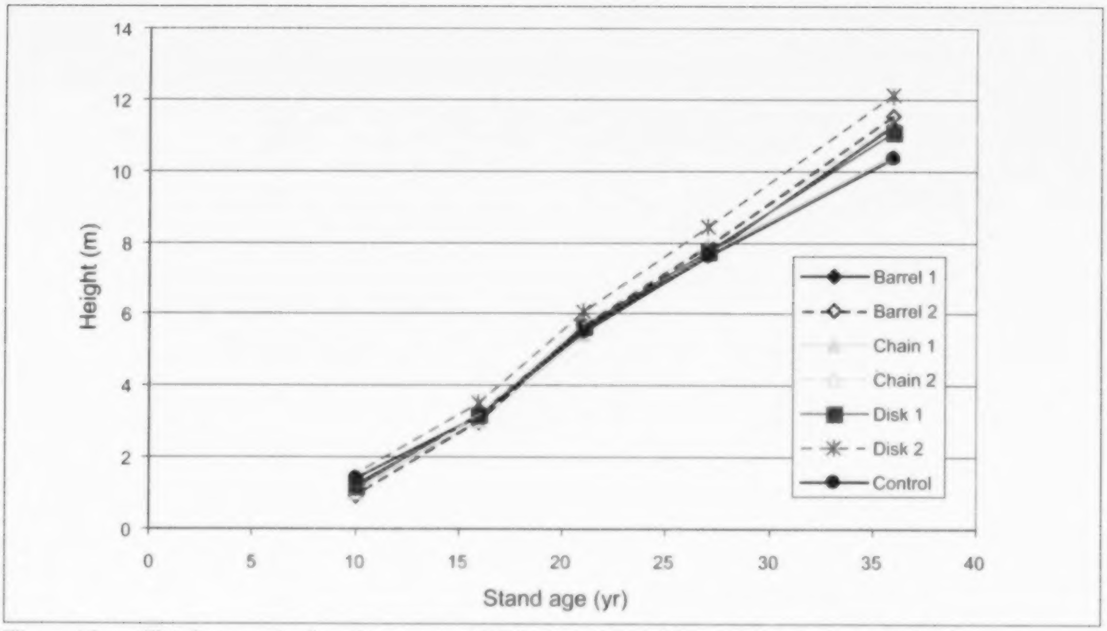

Figure 31. Height growth after thinning in 1977 (at stand age of 10 years) at the Swan Lake site.

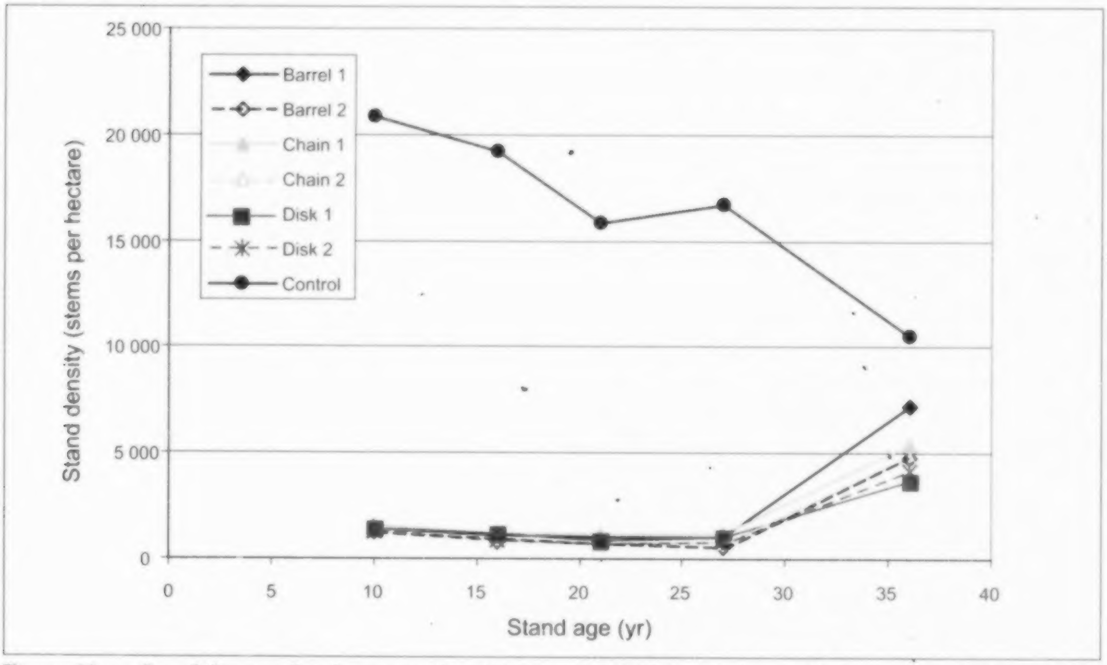

Figure 32. Stand density development after thinning in 1977 (at stand age of 10 years) at the Swan Lake site.

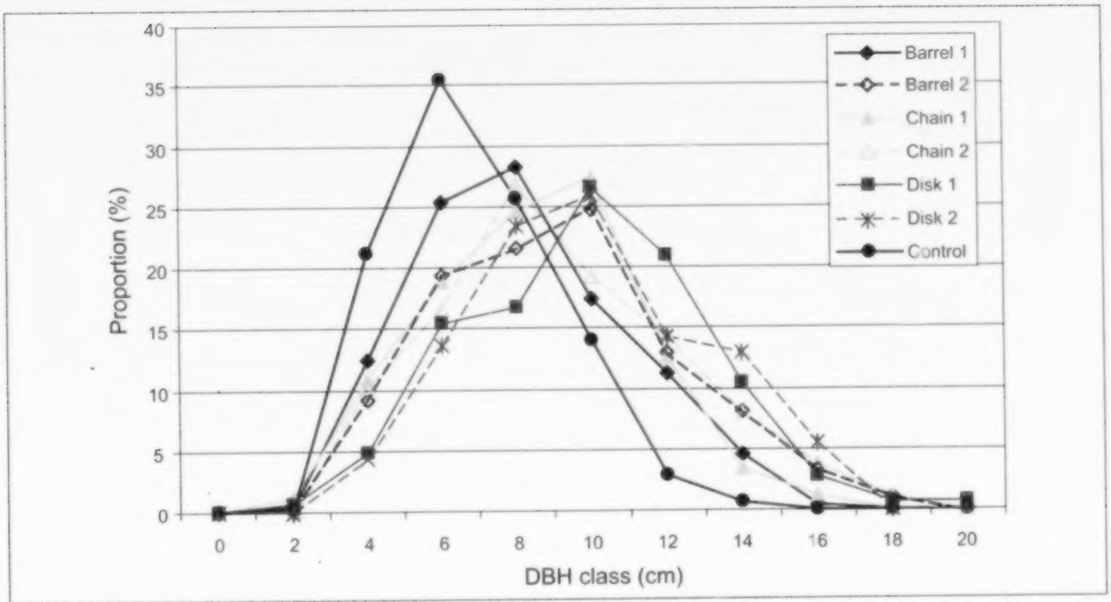

Figure 33. **Diameter distribution, by treatment, 26 years after thinning in 1977 at the Swan Lake site.** DBH = diameter at breast height.

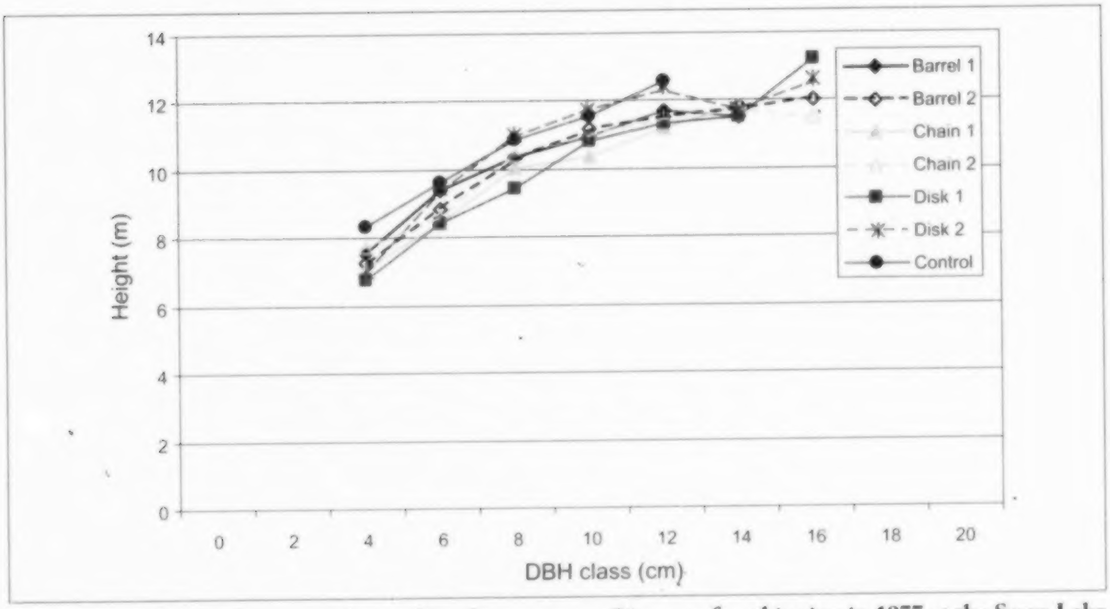

Figure 34. **Height–diameter relationships, by treatment, 26 years after thinning in 1977 at the Swan Lake site.** DBH = diameter at breast height.

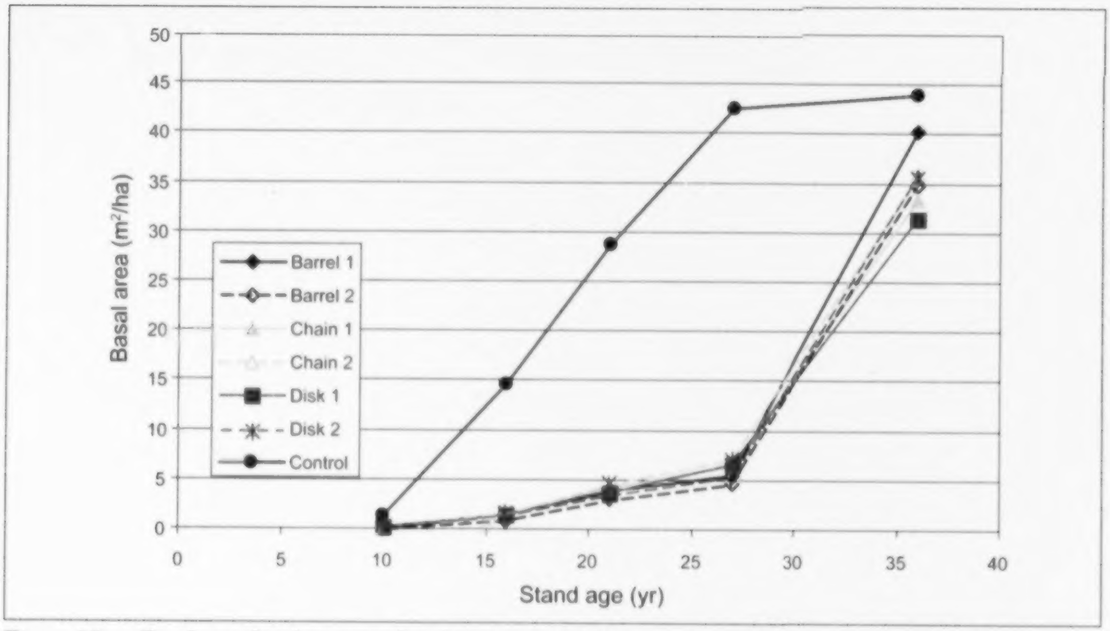

Figure 35. **Basal area development after thinning in 1977 (at stand age of 10 years) at the Swan Lake site.**

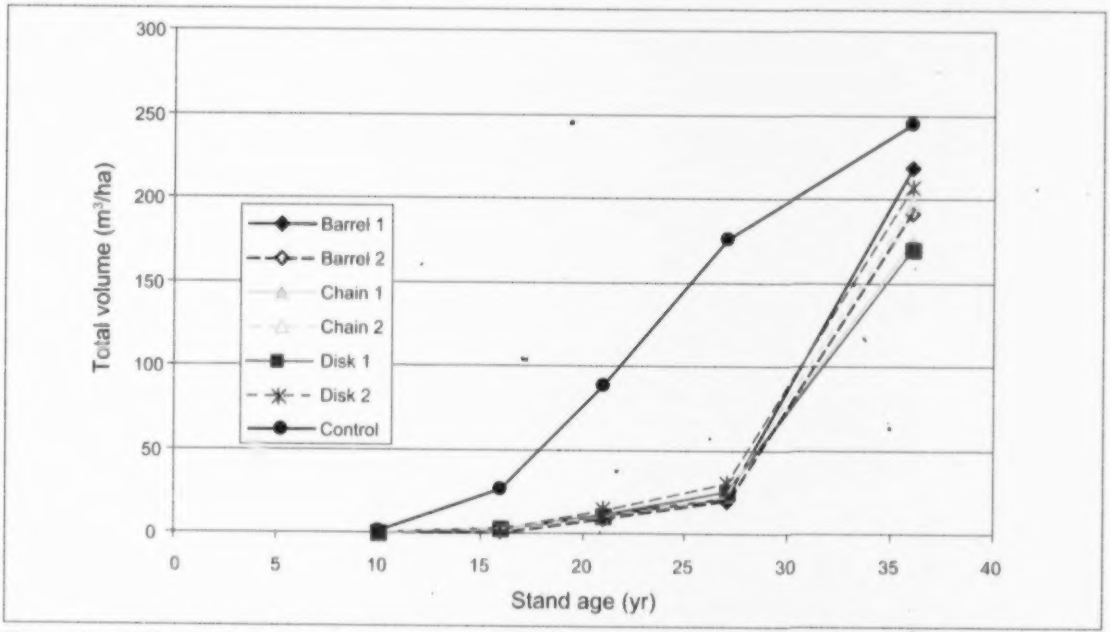

Figure 36. **Total volume development after thinning in 1977 (at stand age of 10 years) at the Swan Lake site.**

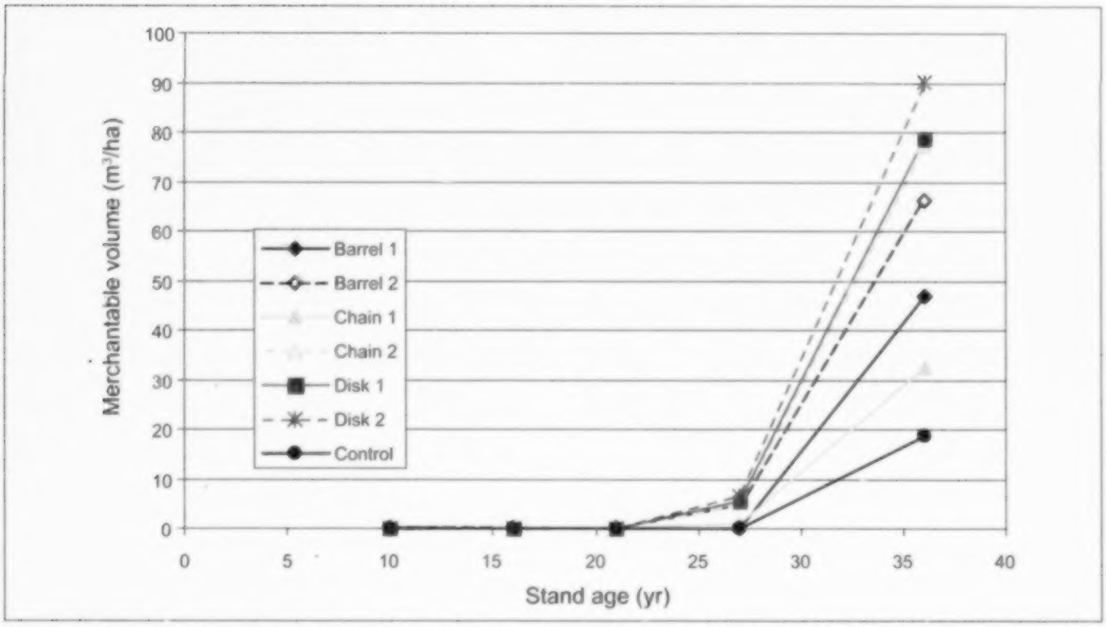

Figure 37. Merchantable volume (13/7 standard) development after thinning in 1977 (at stand age of 10 years) at the Swan Lake site.

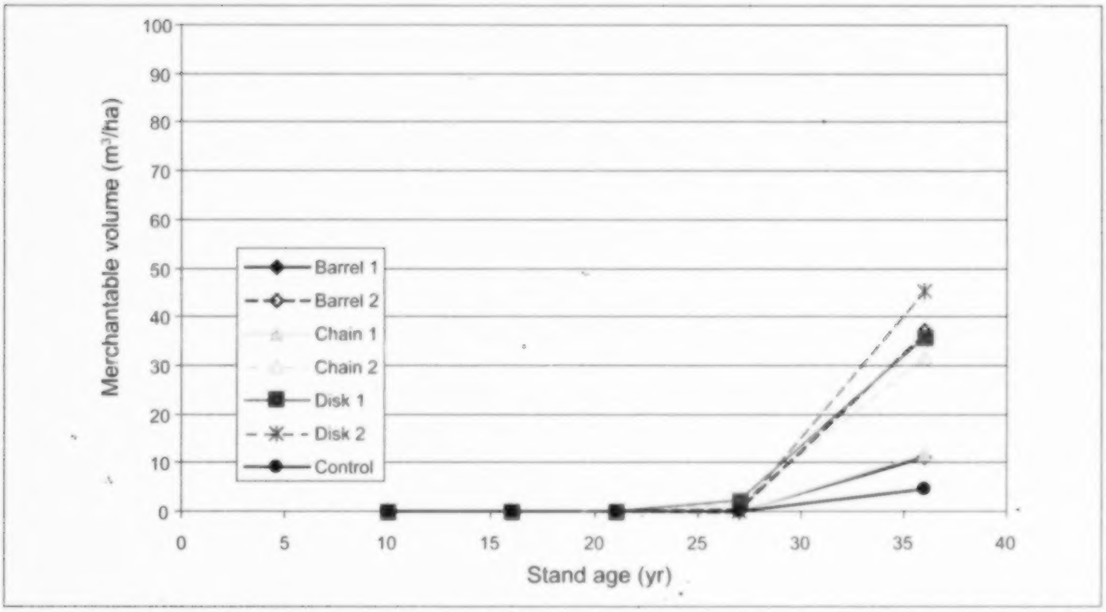

Figure 38. Merchantable volume (15/10 standard) development after thinning in 1977 (at stand age of 10 years) at the Swan Lake site.

Juvenile Spacing Experiments: Overview

The juvenile spacing experiments were established as part of a larger research program designed to examine the effects of initial spacing on the growth of lodgepole pine. This program included the two Gregg Burn spacing experiments, the Teepee Pole Creek spacing experiment, and the Gregg Burn planting trials. The Gregg Burn spacing experimental sites are located about 40 km south of Hinton, Alberta, in an area of pure, even-aged stands of lodgepole pine that regenerated naturally after a 1956 wildfire. These sites encompass two installations, one established in 1963 and the other in 1984. The two installations were subjected to similar spacing treatments, one at stand age 7 years and the other at stand age 28 years. The Teepee Pole Creek experimental sites are located southwest of Rocky Mountain House, Alberta, in an area that also regenerated mostly to pure even-aged lodgepole pine stands after a 1941 wildfire. These sites were established in 1967. Five levels of spacing were tested in the Gregg Burn 1963 and Teepee Pole Creek experiments, and four levels of spacing were tested in the Gregg Burn 1984 experiment. The planting trials were abandoned early on because of very poor survival.

The results from the two Gregg spacing experiments are presented separately in this report. To allow for easier comparison, the scales used to present the data in the figures are consistent for the different sites in the related Gregg Burn and Teepee Pole Creek experiments.

Gregg Burn Seedling Spacing Experiment, Project A-100 (1963)

Establishment and Objectives

The Gregg Burn 1963 spacing experiment was established in 1963–1964 by R.F. Ackerman of the federal Department of Forestry. The experimental sites are located in the Upper Foothills section (B.19c) of the Boreal Forest Region (Rowe 1972), about 40 km south of Hinton, Alberta. The experimental objectives were to examine spacing effects on stand development, to develop size–density and yield relationships from these data as a basis for density management guidelines, and to recommend suitable spacings for juvenile stands on specific sites. Previous publications from this experiment are by Johnstone (1981a) and Yang (1991).

Experimental Design and Treatments

The Gregg Burn 1963 experiment comprised three different sites, classified by productivity (high, medium, and low). Each site was set up as a semirandomized complete-block design with two replicate blocks of treatment plots. Each plot contained 100 uniformly spaced trees, and plot area varied with spacing. The treatments were carried out by setting up a grid of string at the prescribed spacing and tagging the best seedling within 46 cm of each string intersection. All other seedlings were removed by hand. Plots were established at spacings of 1.1, 1.6, 2.3, 3.2, and 4.5 m, corresponding to approximate stand densities of 8000, 4000, 2000, 1000, and 500 stems per hectare. Measurements were taken in 1966 and every 5 years thereafter. Control plots were established in unthinned portions of the stands adjacent to the treated plots for each block of the high and low productivity sites in 1996 and the medium productivity sites in 2004.

Gregg Burn 1963 Spacing Experiment—Low Productivity Site

Location and Access

To access the Gregg Burn (1963) low productivity site (53°14.8'N, 117°21.8'W, legal location NW¼-19-49-23-W5) from Hinton, follow these directions:

Travel west on Highway 16 to the junction with Highway 40.

Turn left (south) on Highway 40 and travel 22.8 km to the Gregg River Road.

Turn left (east) on the Gregg River Road and travel 9.5 km to a small road just before a bridge.

Turn right (south) on the small road and travel 0.6 km up the hill.

Watch for signage on the left, just after the road turns east.

Site Description

The low productivity site is located in the Upper Foothills ecological subregion of west-central Alberta on a flat terrace of sandy glaciofluvial gravels, which support a rapidly drained Eluviated Eutric Brunisol soil with an aeolian veneer and a thin organic layer (Johnstone 1981a). The ecological moisture regime is submesic, and the nutrient regime varies from very poor to poor (Ecotope Consulting Services 1999). This site was classified as having a D1.2 lodgepole pine-black spruce/Labrador tea/feather moss plant community.

Results after 38 Years

Tree Growth and Mortality

The mortality among all treatments was low, below 1% annually, except for the treatment with 8000 stems per hectare at stand age of 45 years (Fig. 39). There appeared to be a period of reduced mortality from 25 to 35 years stand age, followed by a recent rise in mortality. There also appeared to be a trend of increasing mortality rate with increasing stand density, observed mostly in recent measurements (but not for the treatment with 2000 stems per hectare).

From the earliest measurements, the various treatments have been ordered as expected with respect to diameter growth, the lower density treatments showing greater average diameter growth (Fig. 40). Trees in the lowest density treatment, 500 stems per hectare, had an average diameter (16.3 cm) twice that of trees in the highest density treatment (7.9 cm). However, trees in all of the thinned treatments had much greater diameters than those in the control plots, where average diameter is not yet 4 cm; this value is barely half the diameter for the treatment with 8000 stems per hectare, which had the lowest average diameter among all spacing treatments.

As for diameter growth, height growth was greater for the low density treatments, although the relative differences among treatments were less than they were for diameter (Fig. 41). At stand age of 35 years, trees at the lowest density had an average height 2 m taller than those at the highest density. Heights in the lower density treatments were starting to converge at stand age of 45 years. Heights in the control plots were less than half those in any of the spacing treatments.

Stand Development

The stand densities across the treatments declined slowly over time (about 0.5% per year or less), reflecting low rates of both mortality and ingrowth within the treated plots (Fig. 42). Stand density in the control plots, however, showed a sharp decline (2.9% per year) between the two years in which it was measured. On this low productivity site, significant self-thinning apparently occurred only at relatively high stand densities.

As stand density decreased, average diameter increased (Fig. 43). It was expected that individual tree growth would be more vigorous when each tree had more resources (because of wider spacing). The diameter distributions were very similar among the four widest spacings, but the modal value was at least 6 cm less in the treatment with 8000 stems per hectare and 10 cm less in the control plots. The variation in diameter for individual trees in the control plots was less than for any of the treated plots, because of low growth rate and the resulting truncation at the low end of the distribution. The height–diameter curves showed slightly different trajectories for the different treatments; in general, trees within the same diameter class grew taller at higher density than at lower density (Fig. 44).

Basal area per hectare increased with stand density (Fig. 45). Although the growth of individual trees was lower in the denser treatments, these plots had higher basal area per unit stand area because of the higher number of stems that remained. The control plots did not have the greatest basal area per hectare, even though they had the highest number of stems per hectare. At stand age 45 years, the highest density treatments (8000 stems per hectare) had a basal area over three times greater than that of the lowest density treatment (500 stems per hectare), even though average height and diameter were greatest for the lowest density treatment. At the time of the most recent measurements, the basal area of the untreated control plots was closest to that of one of the treatments with intermediate spacing (4000 stems per hectare).

Total volume per hectare increased with increasing stand density among the treatments (Fig. 46). Even though individual tree growth in the higher density treatments was lower than in the lower density plots, the number of stems per hectare was greater, which accounted for the increase in stand volume. However, the total volumes in the control plots were less than the total volumes in three of the five spacing treatments. By stand age 45 years, the two most densely spaced treatments (8000 and 4000 stems per hectare) had the highest total volumes (about 160 m^3/ha), about double the total volume in the control plots, because of the much lower height growth in the control plots. The plots with the lowest total volume per hectare were in the treatment with the lowest stand density and the highest average diameter at breast height and height. However, because there were fewer of these bigger trees per unit area, growing space and resources were underutilized, and the total volume per hectare was just over 50 m^3/ha, less than a third of the total volume per hectare in the most densely spaced treatment (160 m^3/ha).

About 10 years ago, the plots were just beginning to produce merchantable volume, at both merchantability standards (Figs. 47 and 48). Initially, treatments with wider spacing had the highest merchantable volume; the faster growth of the individual trees in those plots allowed them to reach merchantability sooner. However, in the most recent measurement interval, the increase in merchantable volume was greater in plots with higher stand densities. The increase in merchantable volume was leveling off in plots with lower densities but was still increasing in plots with higher densities. The next few measurement intervals will be of particular interest, as they will demonstrate whether these trends continue over the longer term.

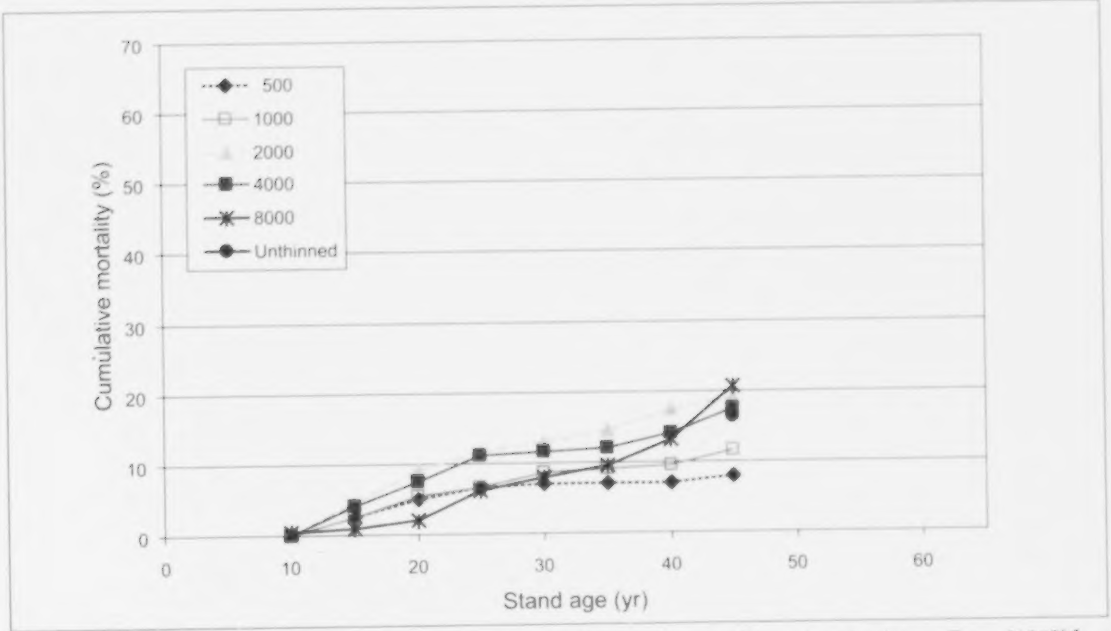

Figure 39. **Cumulative mortality after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

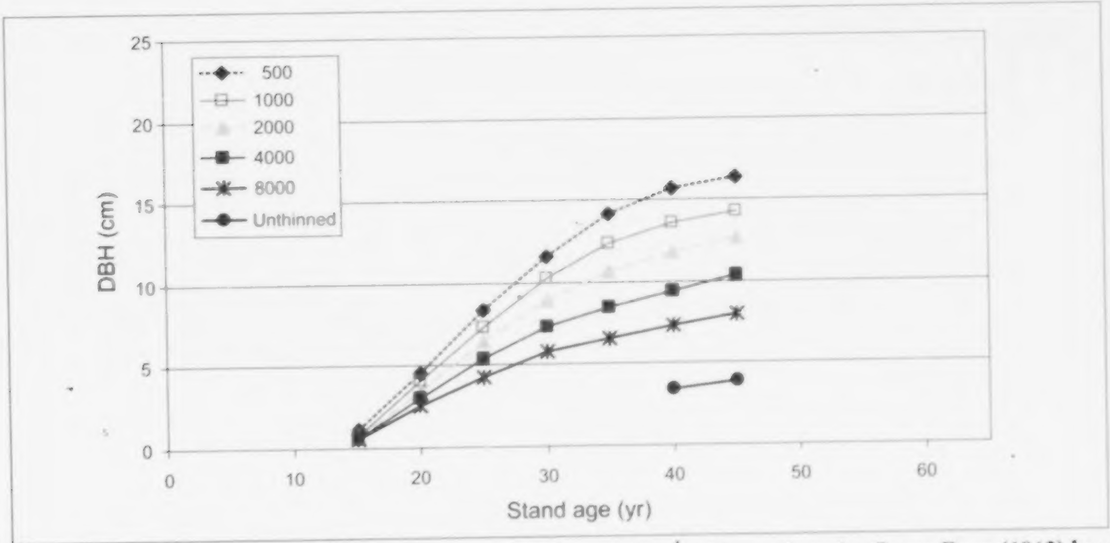

Figure 40. **Diameter growth after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

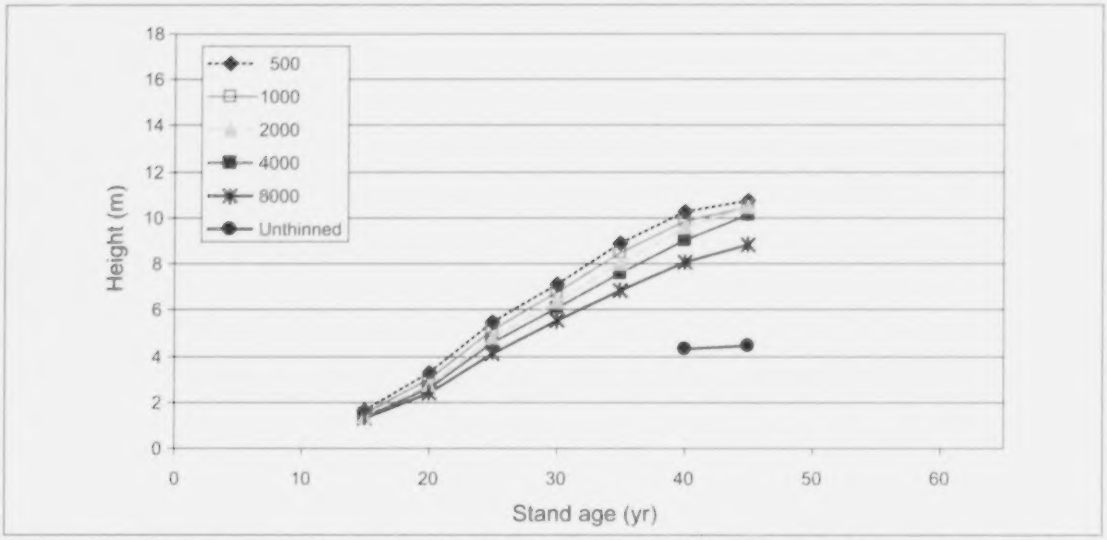

Figure 41. **Height growth after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

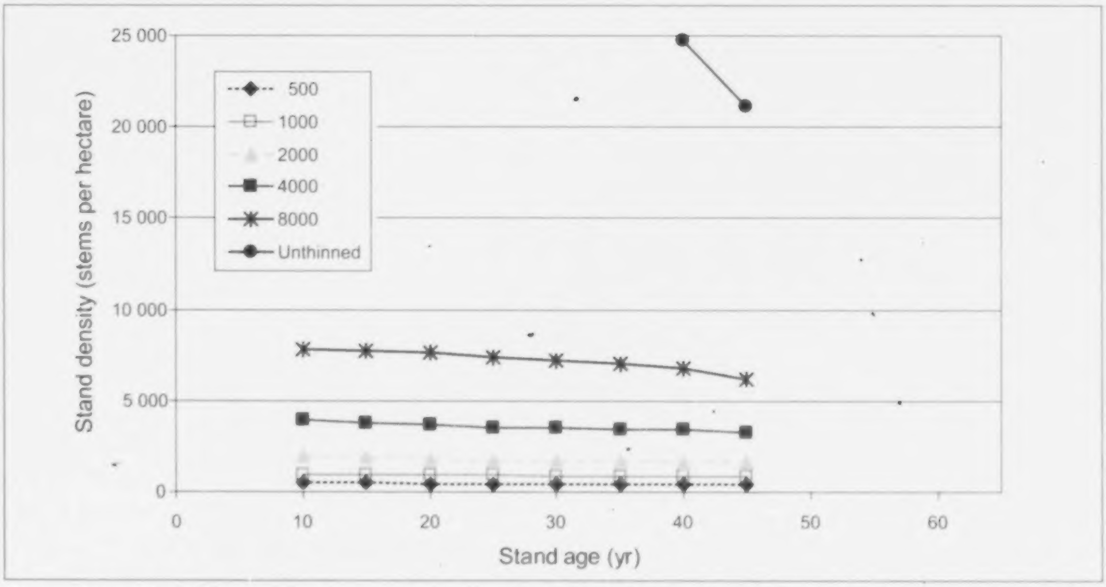

Figure 42. **Stand density development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

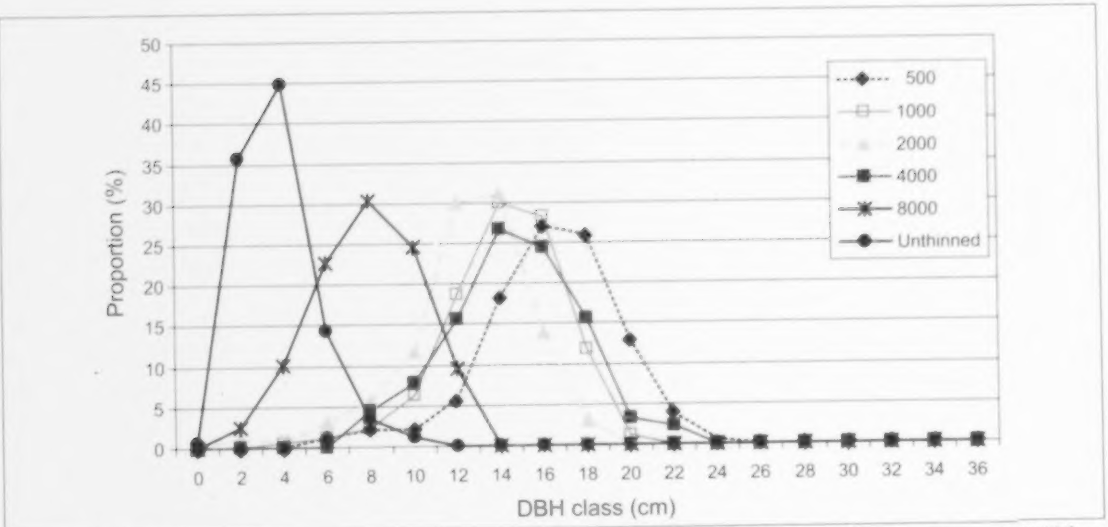

Figure 43. **Diameter distribution, by treatment, 38 years after spacing in 1963 at the Gregg Burn (1963) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

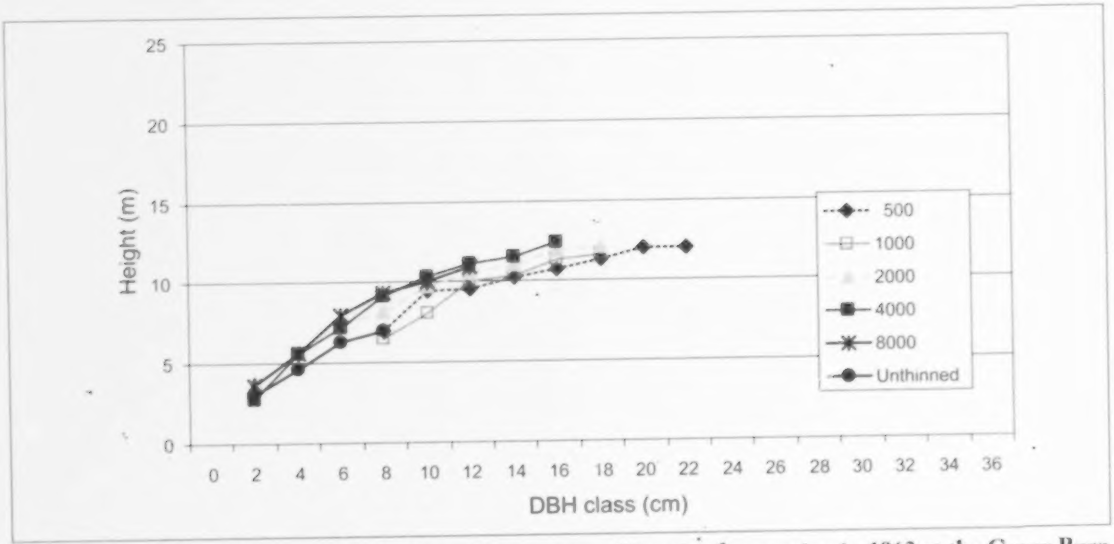

Figure 44. **Height–diameter relationships, by treatment, 38 years after spacing in 1963 at the Gregg Burn (1963) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

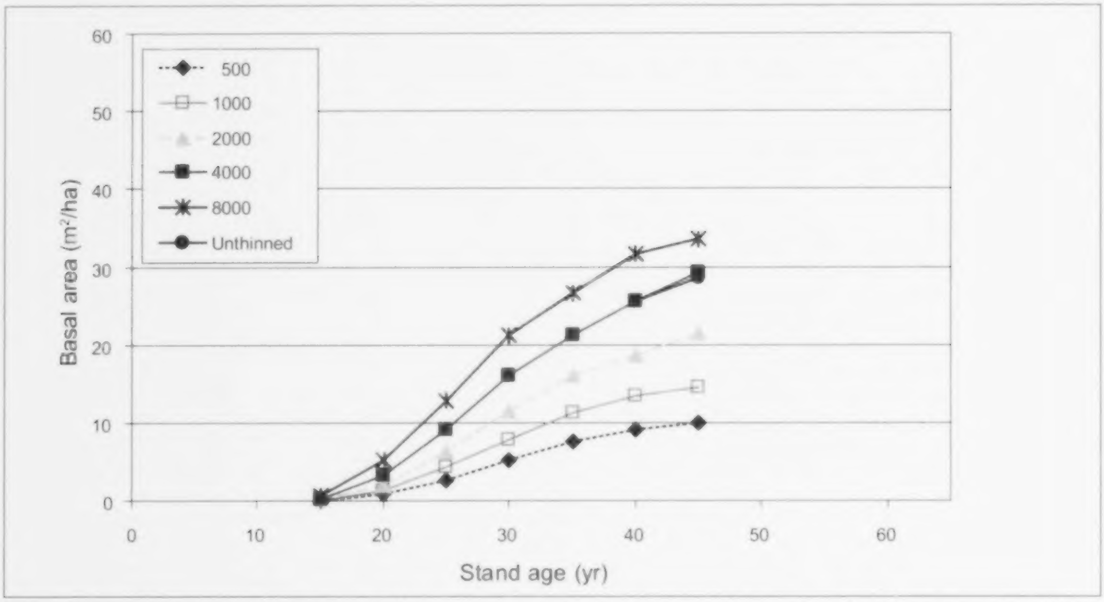

Figure 45. **Basal area development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

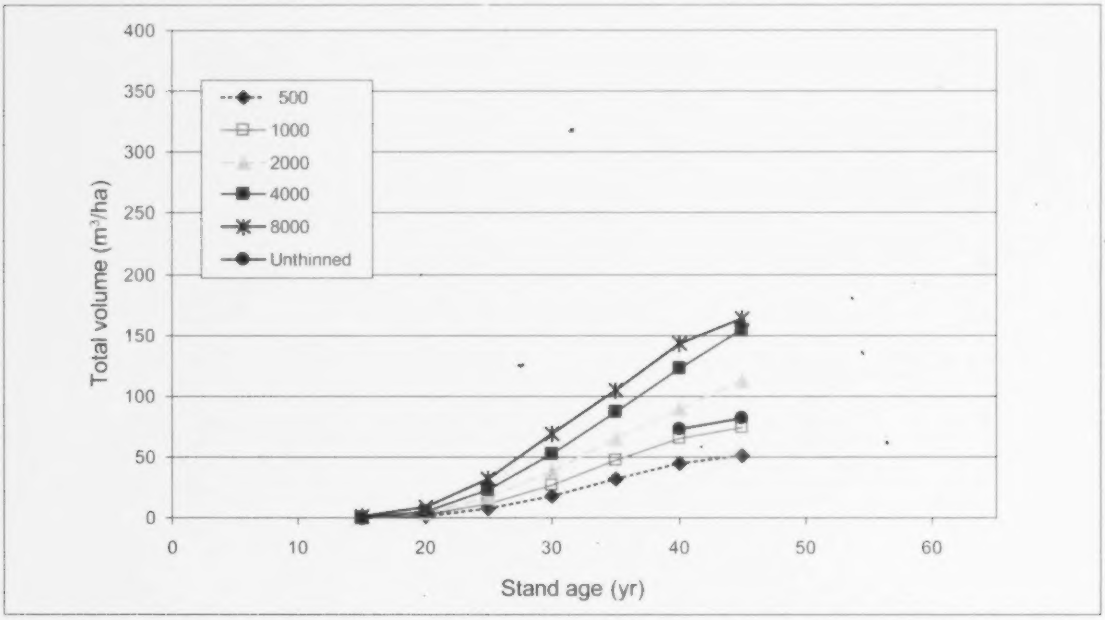

Figure 46. **Total volume development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

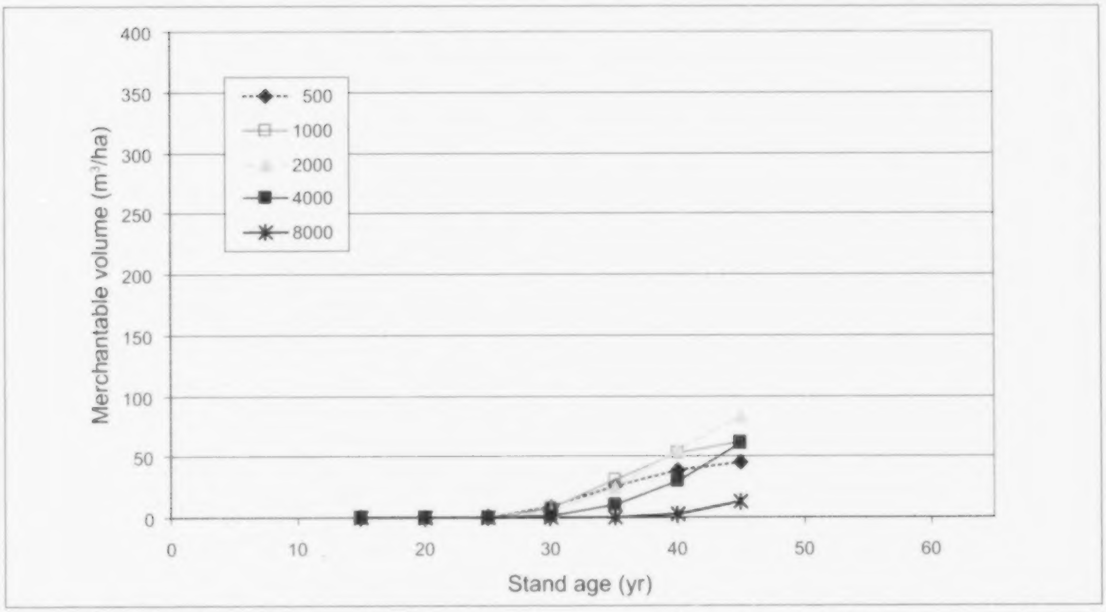

Figure 47. Merchantable volume (13/7 standard) development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) low productivity site. Treatments are designated by stand density after thinning (stems per hectare).

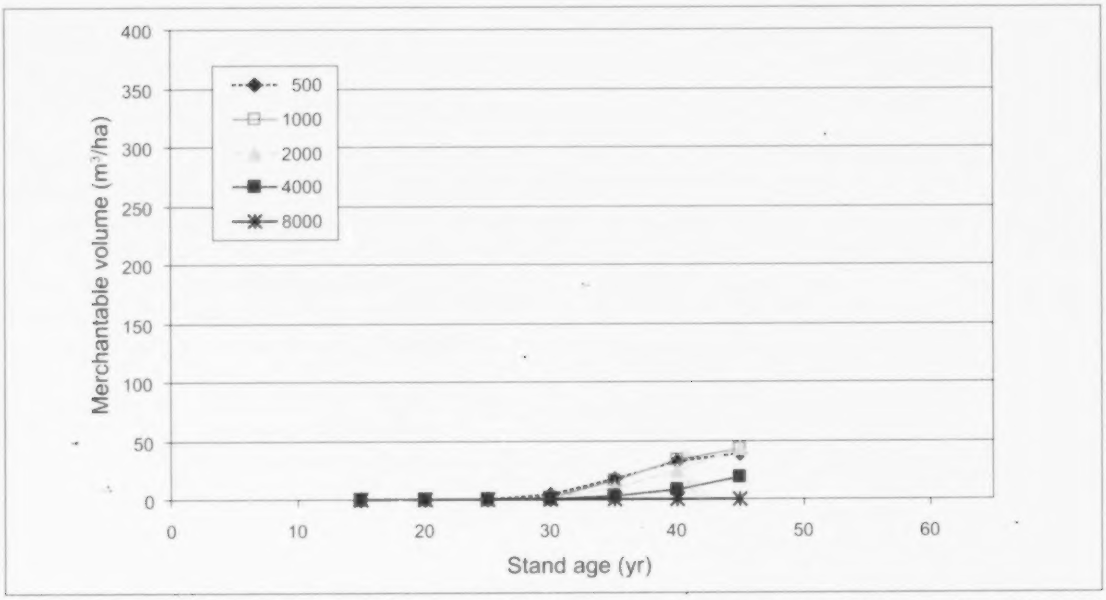

Figure 48. Merchantable volume (15/10 standard) development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) low productivity site. Treatments are designated by stand density after thinning (stems per hectare).

Gregg Burn 1963 Spacing Experiment–Medium Productivity Site

Location and Access

To access the Gregg Burn (1963) medium productivity sites (53°13.6'N, 117°21.1'W, legal location 6/7/11-18-49-23-W5) from Hinton, follow these directions:

Travel west on Highway 16 to the junction with Highway 40.

Turn left (south) on Highway 40 and travel 22.8 km to the Gregg River Road.

Turn left (east) on the Gregg River Road and travel 8.2 km to the Tri-Creeks Road.

Turn right (south) on the Tri-Creeks Road and travel 2.8 km.

Watch for signage for the first replicate block on the left.

To reach the second replicate, travel 200 m farther south down the road.

Turn left (east) and cross the clearing to the trail in the southeast corner.

The sign for the block is 290 m from the road.

Site Description

The medium productivity sites are located in the Upper Foothills ecological subregion of west-central Alberta on south to southwest aspect slopes, with grade varying from 5% to 25%. Soils are moderately well-drained Brunisolic Gray Luvisols developed on sandy loam to clay loam textured cordilleran till with fluvioeolian veneer (Johnstone 1981a). The ecological soil moisture regime is mesic, and the nutrient regime is poor (Ecotope Consulting Services 1999). This site was classified as having an E1.3 lodgepole pine/ Labrador tea/feather moss plant community.

Results after 38 Years

Tree Growth and Mortality

Mortality among all treatments was higher at the medium productivity site (Fig. 49) than at the low productivity site (Fig. 39). In general, the higher density treatments experienced higher mortality; however, mortality was lowest in the treatment with 1000 stems per hectare. Although its mortality was consistently lower than in the treatment with 2000 stems per hectare, a sharp rise in mortality in the treatment with 4000 stems per hectare at stand age of 45 years brought its cumulative mortality close to that of the treatment with 2000 stems per hectare. The mortality trend over time that was observed at the low productivity site (high – low – high) was also seen at the medium productivity site.

As at the low productivity site, diameter growth increased with increasing spacing (Fig. 50). As expected, the rate of increase was higher than at the low productivity site (by approximately 10–20%). The lowest density treatment had trees with an average diameter approximately double that of the highest density treatment. Height growth appeared to follow two distinct trajectories, a lower one for the treatments with 4000 and 8000 stems per hectare and a higher one for less dense treatments (Fig. 51). At stand age 45 years, trees growing at lower densities were approximately 2 m taller than those growing at higher densities.

Stand Development

The stand densities in the plots with wider spacings showed little change over time (Fig. 52), which reflected low mortality in these plots. The number of trees in the treatments with denser spacing showed a small but steady decline. Ingrowth into all of the treated plots was negligible.

The diameter distributions again illustrated that as stand density decreased, the individual tree diameter increased in response to availability of more resources per tree (Fig. 53). Diameter distribution curves were shifted farther to the right (i.e., average diameters were larger) and were more evenly spaced than for the low productivity site, but the distribution for the control plots was still somewhat truncated on the left. Height–diameter relationships among the treatments were similar;

however, in the larger diameter classes, trees in plots with wider spacing appeared to be shorter for a given diameter class (Fig. 54).

The basal area per hectare increased with density (Fig. 55). The trade-off between number of stems and diameter growth is clearly demonstrated by the treatments with 1000 and 2000 stems per hectare, which have closely paralleled each other in their basal area development. By stand age 45 years, the least dense treatment (500 stems per hectare) had produced only 13 m^2/ha of basal area, less than half that for the treatment with 4000 stems per hectare (29 m^2/ha) and little more than a third of that for the treatment with 8000 stems per hectare (35 m^2/ha). All treatments showed evidence of decreasing rate of basal area growth over the most recent measurement interval.

The higher density treatments had higher total volumes per hectare (Fig. 56), closely following the trends in basal area development. At stand age 45 years, the total volume for the highest density treatment was more than 100 m^3/ha greater than that for the lowest density treatment.

This stand has been producing merchantable volume for the past 20 years (Figs. 57 and 58), about 5 years longer than has been the case at the low productivity site. The intermediate spacings, particularly 1000 stems per hectare, have produced the greatest merchantable volumes. At younger ages, the most widely spaced treatment had merchantable volumes similar to those of the treatments with 1000 and 2000 stems per hectare, which reflected the greater potential of individual trees to reach merchantability in those treatments. However, as stand development continued, the effect of higher stand densities allowed the merchantable volume of the two intermediate treatments to catch up and surpass that of the treatment with 500 stems per hectare. The next few measurements can be expected to show a change in the ranking of the treatments as more of the volume in the higher density treatments moves above the merchantability threshold.

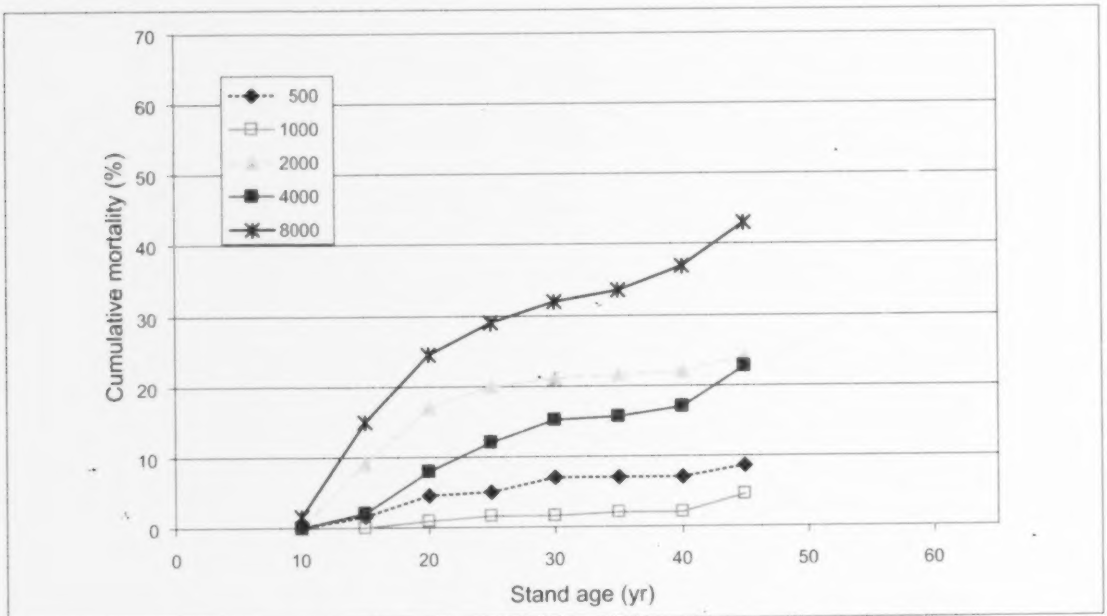

Figure 49. **Cumulative mortality after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

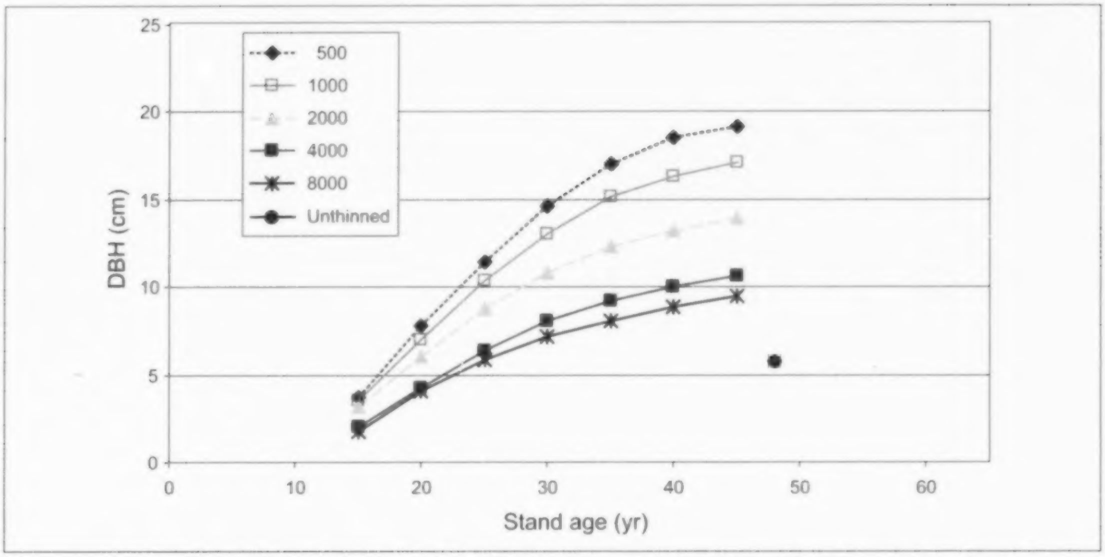

Figure 50. **Diameter growth after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

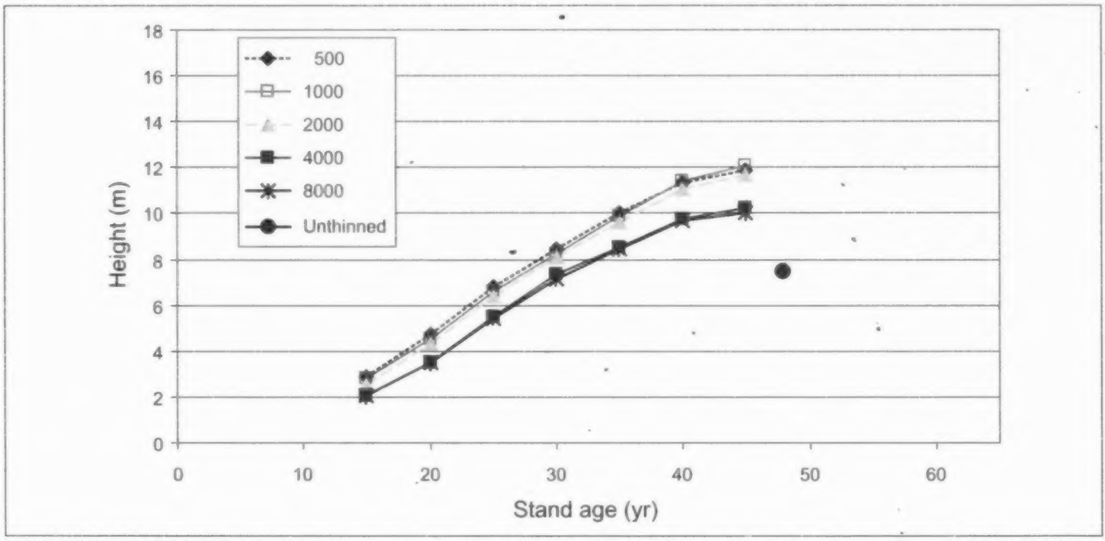

Figure 51. **Height growth after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

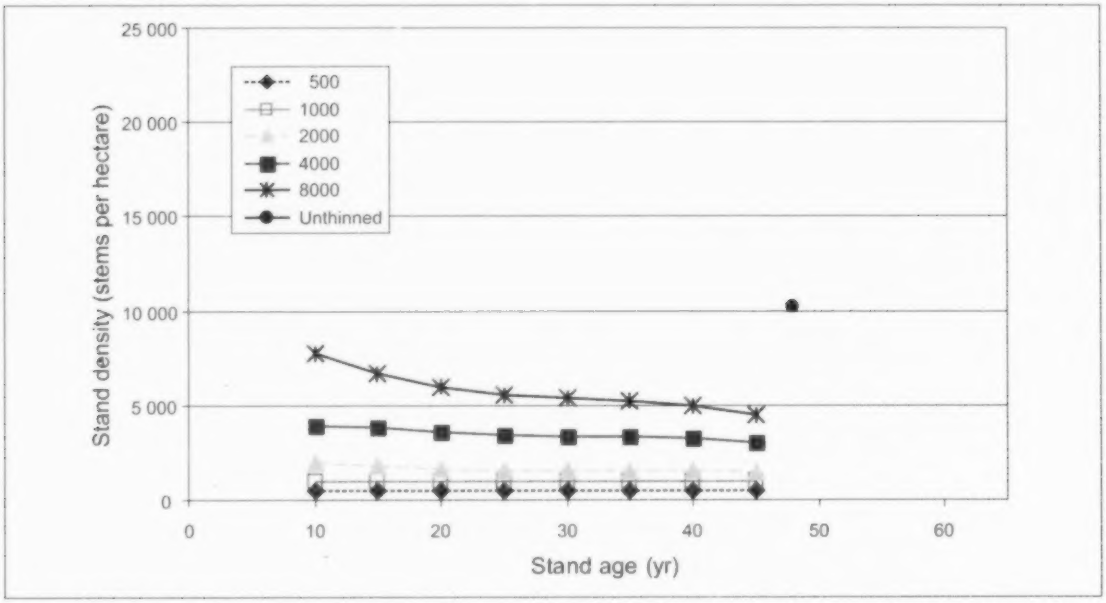

Figure 52. **Stand density development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

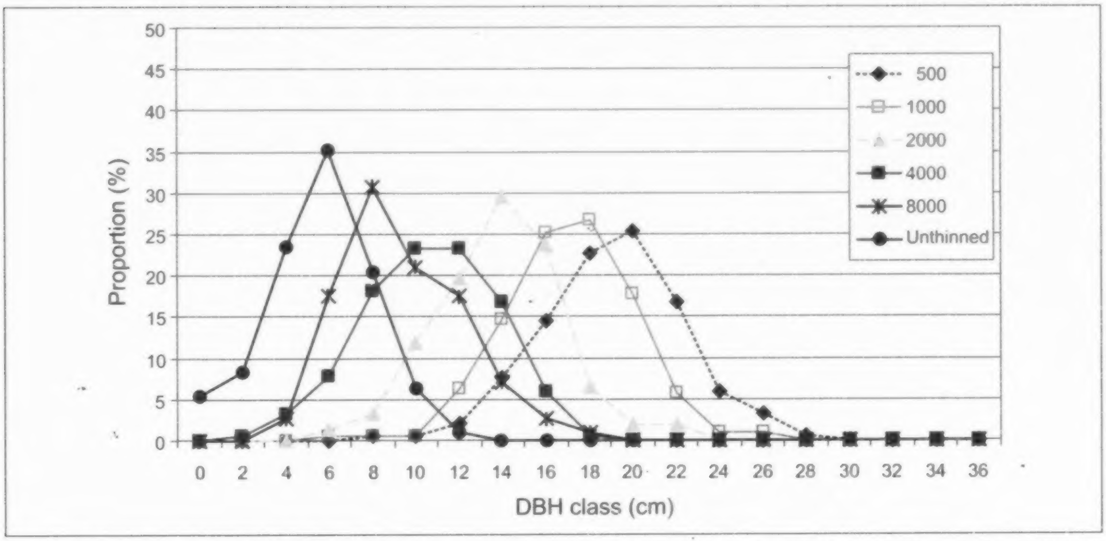

Figure 53. **Diameter distribution, by treatment, 38 years after spacing in 1963 at the Gregg Burn (1963) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

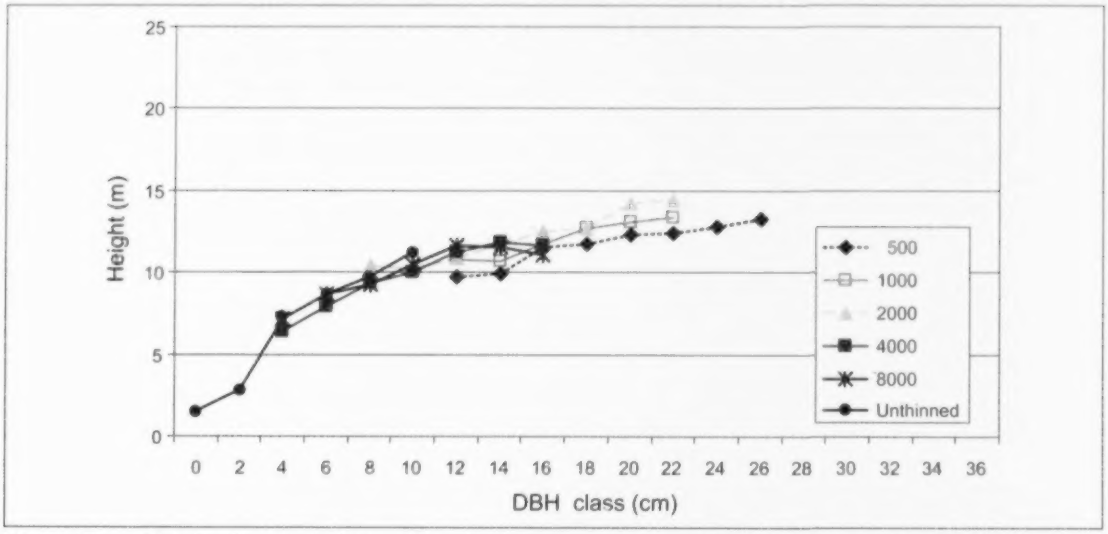

Figure 54. Height–diameter relationships, by treatment, 38 years after spacing in 1963 at the Gregg Burn (1963) medium productivity site. Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

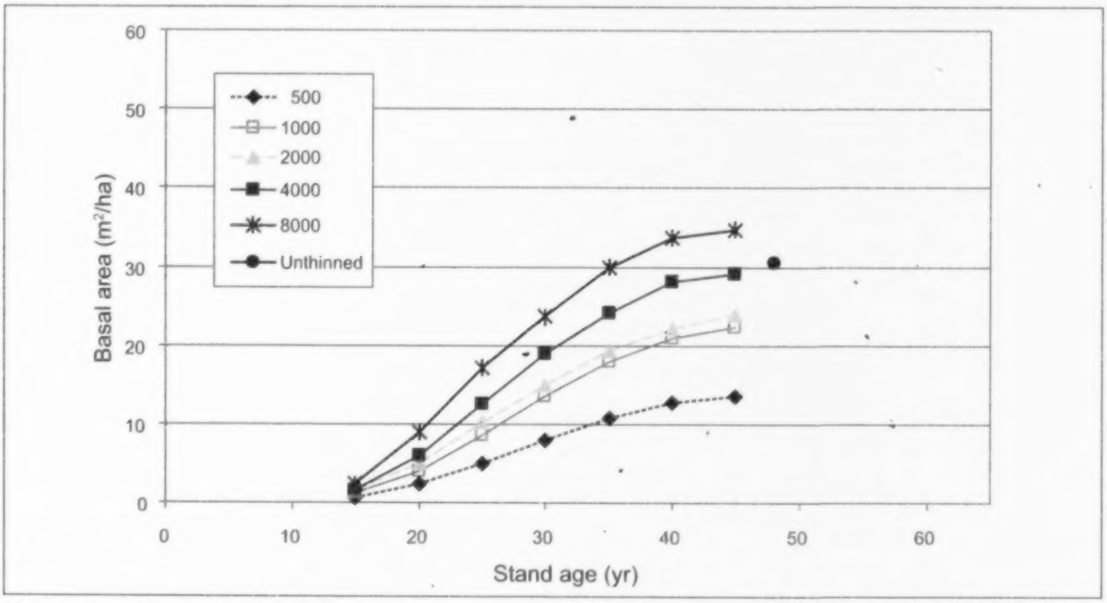

Figure 55. Basal area development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) medium productivity site. Treatments are designated by stand density after thinning (stems per hectare).

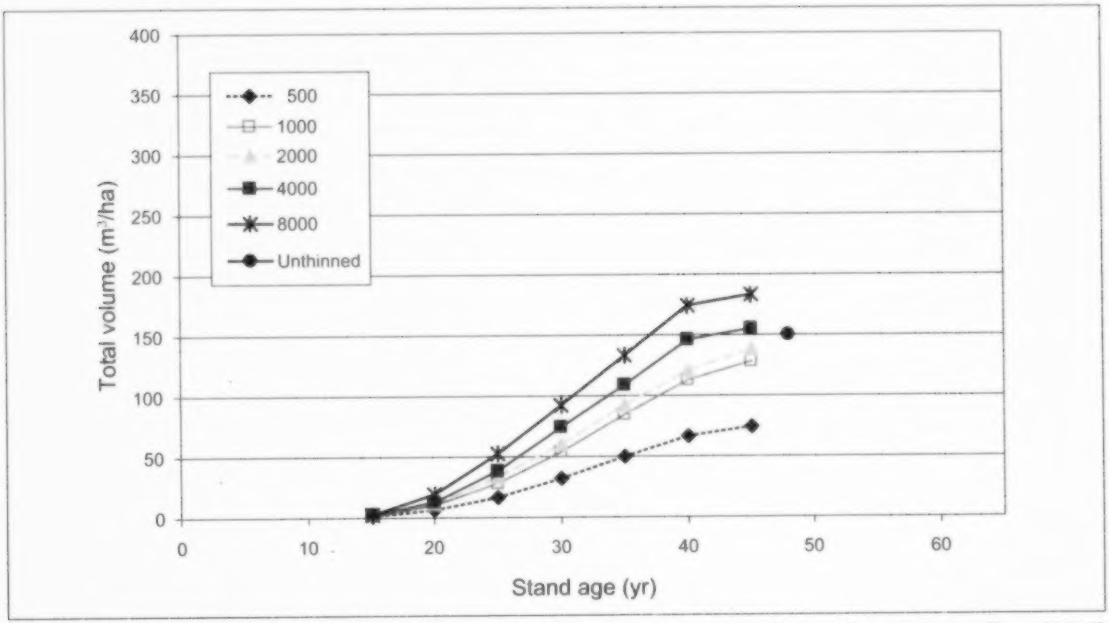

Figure 56. **Total volume development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

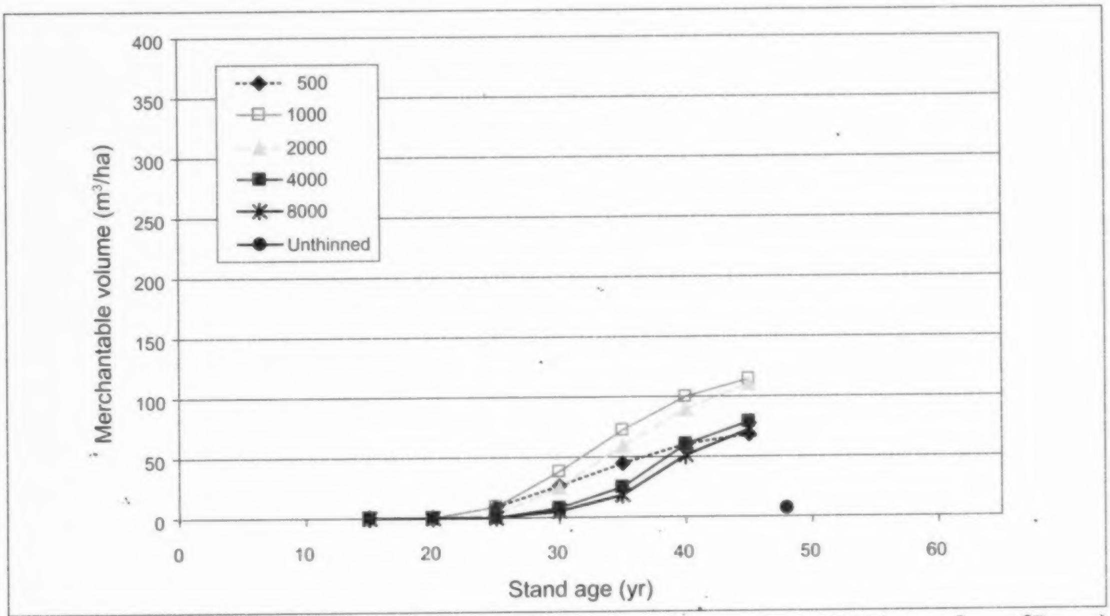

Figure 57. **Merchantable volume (13/7 standard) development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

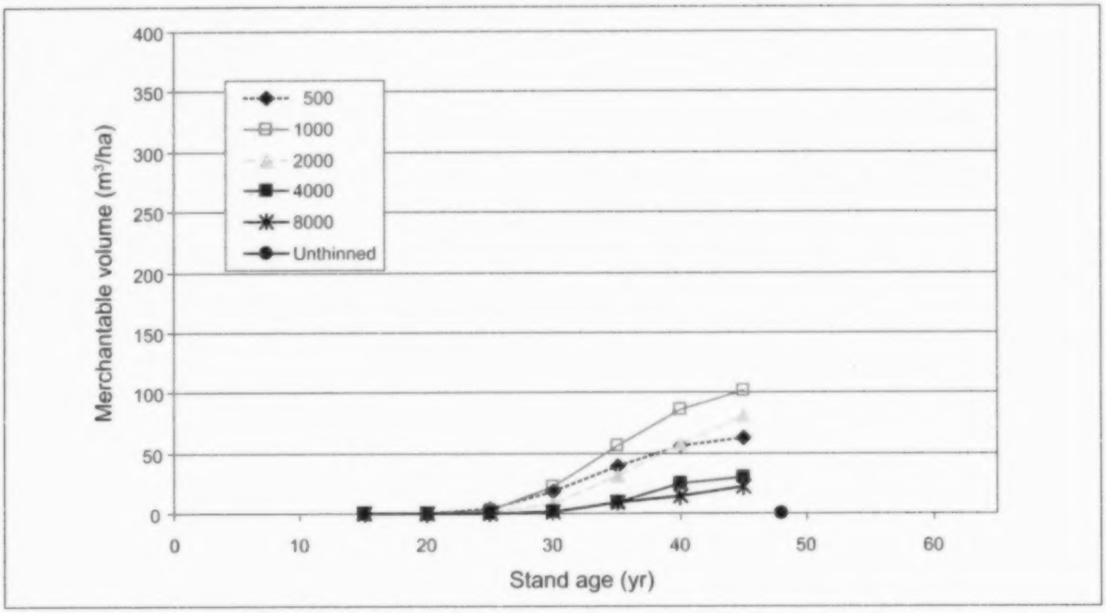

Figure 58. **Merchantable volume (15/10 standard) development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

Gregg Burn 1963 Spacing Experiment—High Productivity Site

Location and Access

To access the Gregg Burn (1963) high productivity sites (53°14.1'N, 117°22.0'W, legal location 13/18/19/24-49-24-W5) from Hinton, follow these directions:

Travel west on Highway 16 to the junction with Highway 40.

Turn left (south) on Highway 40 and travel 22.8 km to the Gregg River Road.

Turn left (east) on the Gregg River Road and travel 8.2 km to the Tri-Creeks Road.

Turn right (south) on the Tri-Creeks Road and travel 1.8 km.

Watch for signage on the left.

Site Description

The high productivity sites are located in the Upper Foothills ecological subregion of west-central Alberta on different slopes: block 3 on a southwest aspect midslope and block 4 on a northeast aspect upper slope. Grades vary from 0% to 25%. Soils are sandy loam Eluviated Eutric Brunisols, coarse-textured in block 3 and fine-textured in block 4. The ecological soil moisture regime varies from mesic to subhygric, and the nutrient regime varies from medium-poor to medium-rich (Ecotope Consulting Services 1999). This site was classified as having an E1.1 lodgepole pine/green alder/feather moss plant community.

Results after 38 Years

Tree Growth and Mortality

Mortality was greater at the high productivity site than at the medium and low productivity sites of the Gregg Burn; mortality was also most varied at the high productivity site, ranging from near 0% to more than 5% annually (Fig. 59). Generally, mortality increased with increasing stand density; however, as at the low and medium productivity sites, early mortality was unusually high in the treatment with 2000 stems per hectare. The treatment with 8000 stems per hectare had unexpectedly low mortality for the first 10 years after plot establishment; however, high mortality in the most recent decade has resulted in the highest cumulative mortality among the treatments at age 45 years. A period of lower mortality lasting 10 to 15 years in the middle of the measurement period was also seen here, although not as consistently as at the low and medium productivity sites.

From the outset, diameter growth varied inversely with stand density (Fig. 60). At the latest measurement, at stand age of 45 years, the average diameter was nearly 22 cm for trees in the lowest density treatment (500 stems per hectare) and less than 14 cm for those in the highest density treatment (8000 stems per hectare). Average diameters were approximately 15% to 40% greater than at the medium productivity site. Height showed little variation among spacing treatments at the high productivity site (Fig. 61). From the first measurement to the latest, at age 45 years, average heights from all five spacing treatments were within 1 m of each other.

Stand Development

Stand density showed little change over time at the two widest spacings (Fig. 62), which reflected the low mortality in these plots. The three more tightly spaced treatments had a moderate but steady decline in numbers, and densities at age 45 years were less than those at the medium productivity site. Ingrowth into these plots was negligible.

At the high productivity sites, the diameter distributions were shifted even farther to the right than was the case for the low and medium productivity sites, and the trend of increasing distribution mean with decreasing stand density was maintained (Fig. 63). However, there was more variability at the high productivity site than at the other sites, as indicated by the broader distributions observed at all densities and their greater overlap. Differences in height–diameter relationships were not entirely consistent at these sites, but there appeared to be some differentiation among the treatments. Wider spacings tended to have lower heights for a given diameter class than closer spacings (Fig. 64).

Trends in stand basal area were very similar to those at the medium productivity site, although the difference among treatments was larger (Fig. 65). Again, basal area development was nearly identical for the treatments with 1000 and 2000 stems per hectare, illustrating the trade-off between number of stems and average tree size. At age 45 years, the basal areas of the three widest spaced treatments were similar to those at the medium productivity site, whereas the basal area of the most closely spaced treatments (4000 and 8000 stems per hectare) were much higher at the high productivity site (32 m^2/ha and 46 m^2/ha, respectively) than at the medium productivity site (29 m^2/ha and 34 m^2/ha, respectively). Recent mortality among larger trees reduced basal area in the treatments with 2000 and 8000 stems per hectare over the last 5 years of the measurement period.

As at the medium productivity site, total volume trends at the high productivity site (Fig. 66) followed those of basal area development, reflecting the relatively small differences in height development among the treatments. At stand age 45 years, the most closely spaced treatment had about 3.5 times the volume of the most widely spaced treatment.

The faster growth of trees at this site than at the low and medium productivity sites produced more merchantable volume earlier in stand development. By age 30 years, the denser treatments had caught up to less dense treatments in terms of merchantable volumes (for the 13/7 standard), and by the next measurement had surpassed them (Fig. 67). At the most recent measurement, the highest stand density treatment (8000 stems per hectare) had about 220 m^3/ha merchantable volume, whereas the lowest density treatment (500 stems per hectare) had less than 75 m^3/ha. The development of merchantable volume at the 15/10 standard showed similar trends, but the crossover point, where denser treatments overtook less dense treatments, occurred 5 to 10 years later (Fig. 68).

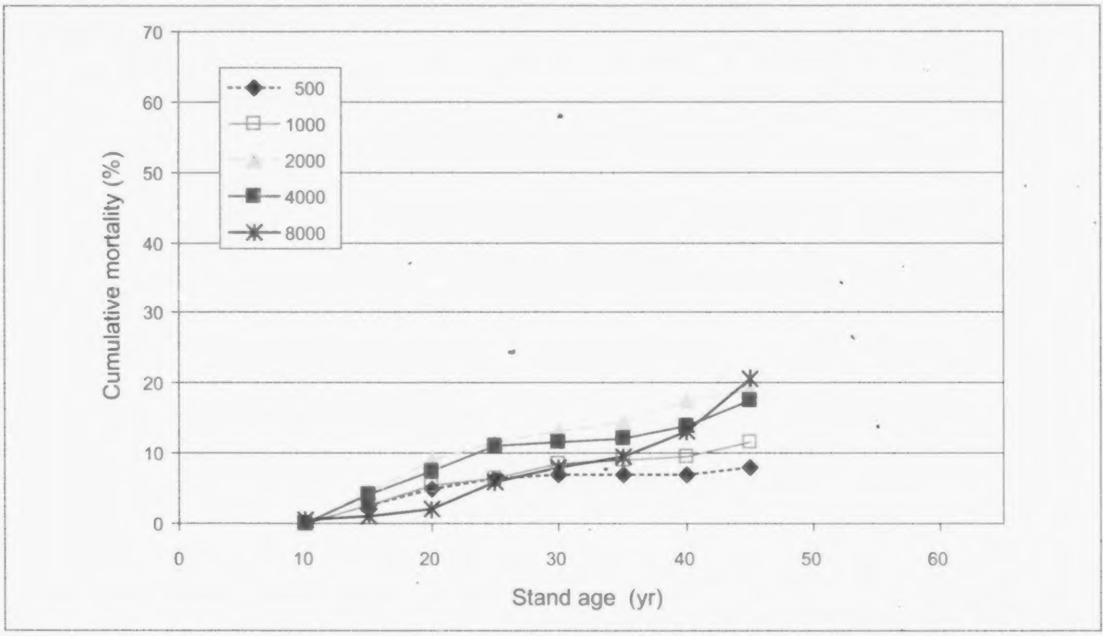

Figure 59. Cumulative mortality after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) high productivity site. Treatments are designated by stand density after thinning (stems per hectare).

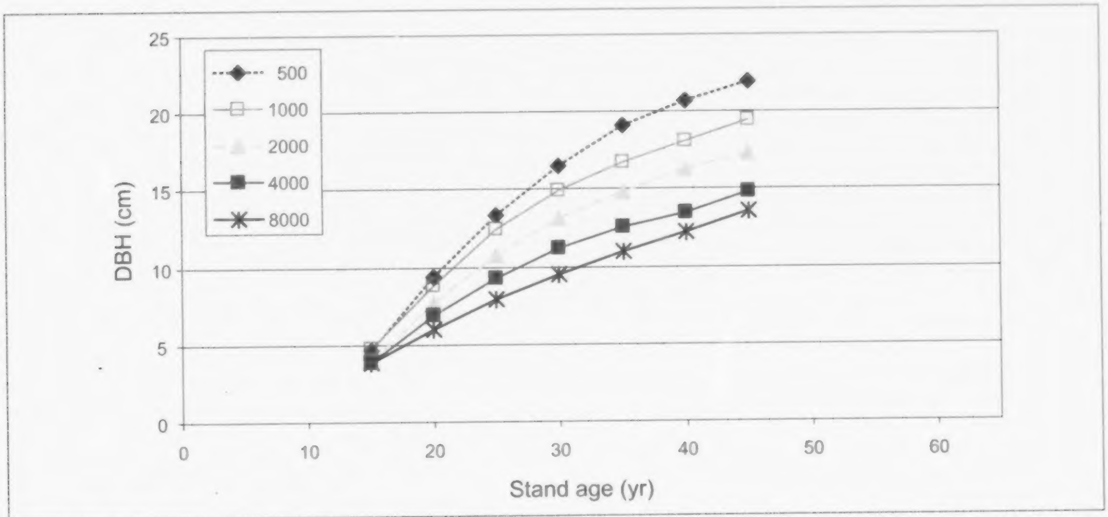

Figure 60. **Diameter growth after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

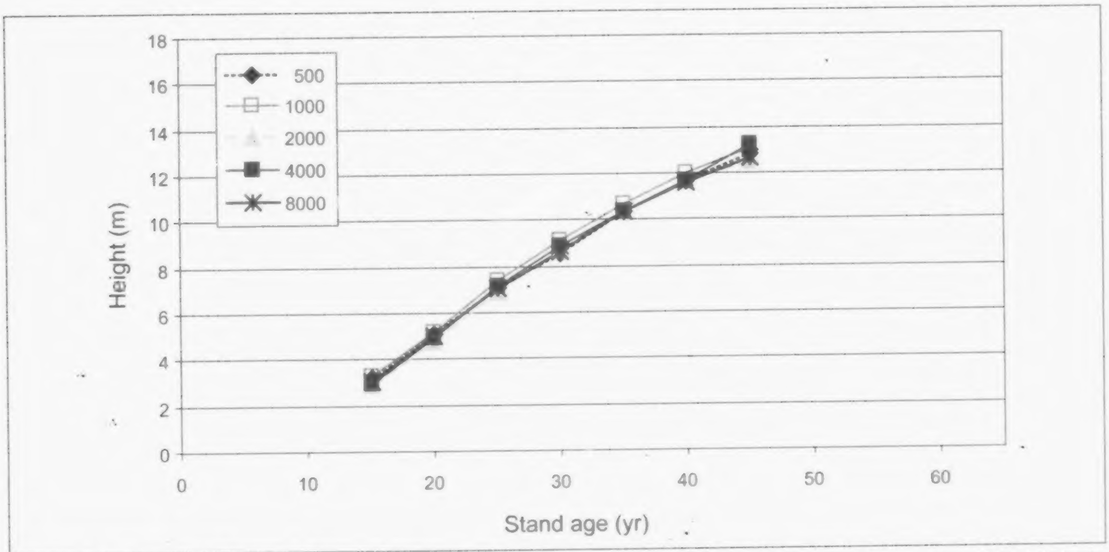

Figure 61. **Height growth after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

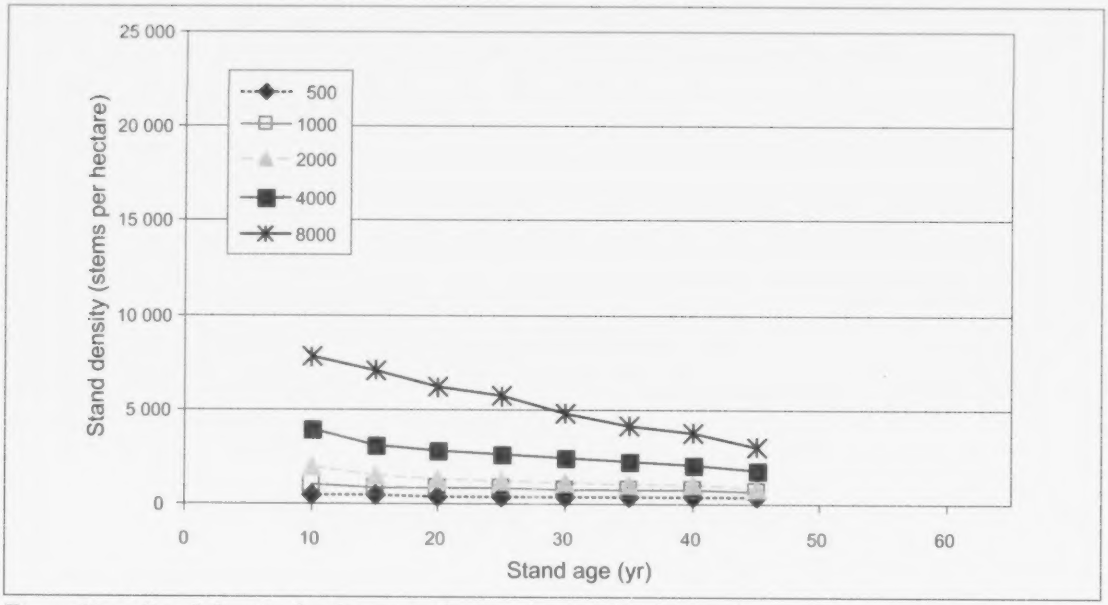

Figure 62. **Stand density development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

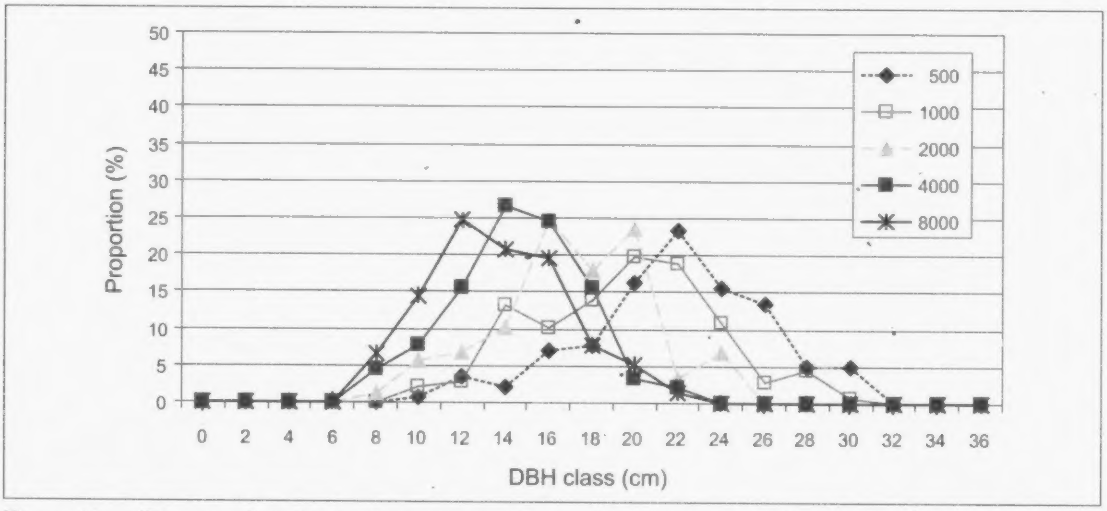

Figure 63. **Diameter distribution, by treatment, 38 years after spacing in 1963 at the Gregg Burn (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

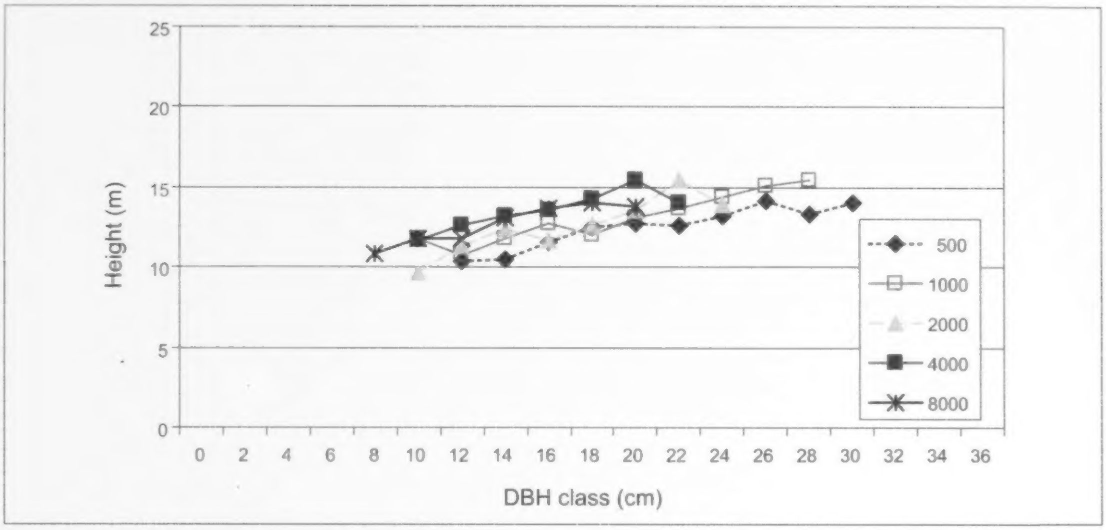

Figure 64. **Height–diameter relationships, by treatment, 38 years after spacing in 1963 at the Gregg (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

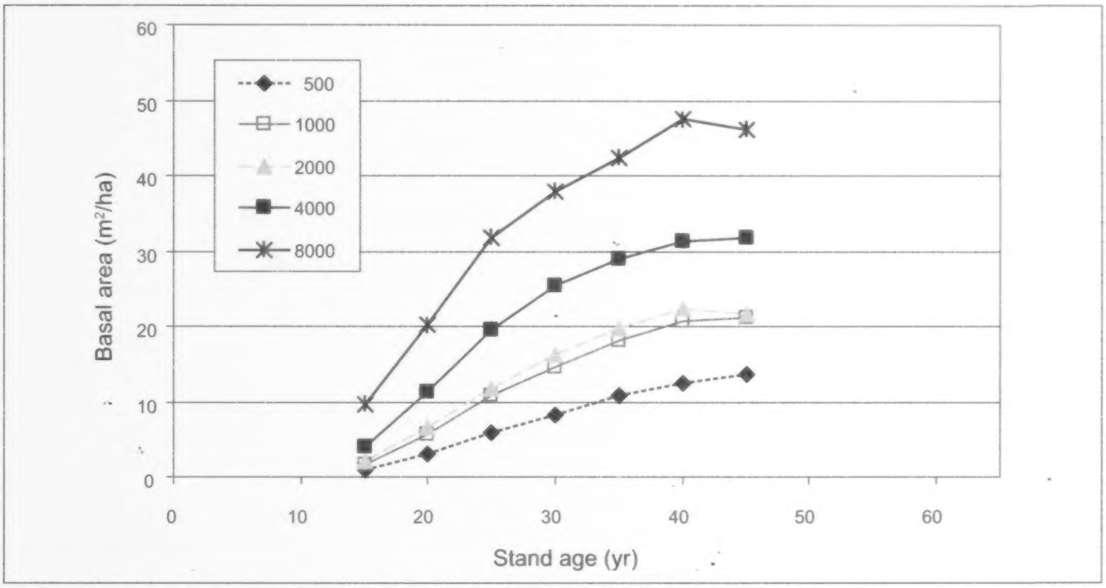

Figure 65. **Basal area development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

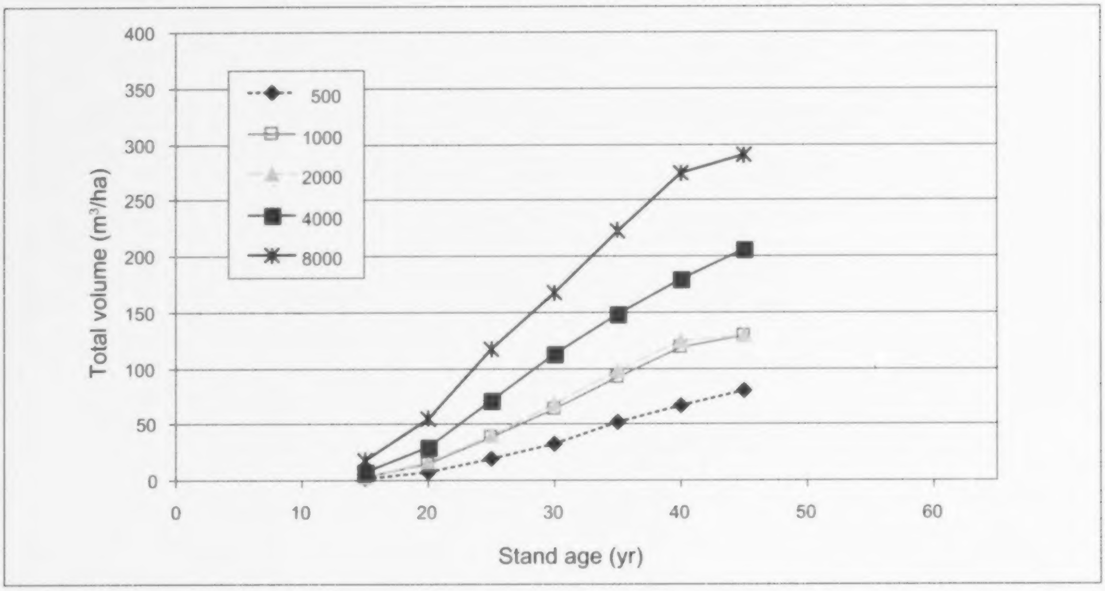

Figure 66. **Total volume development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

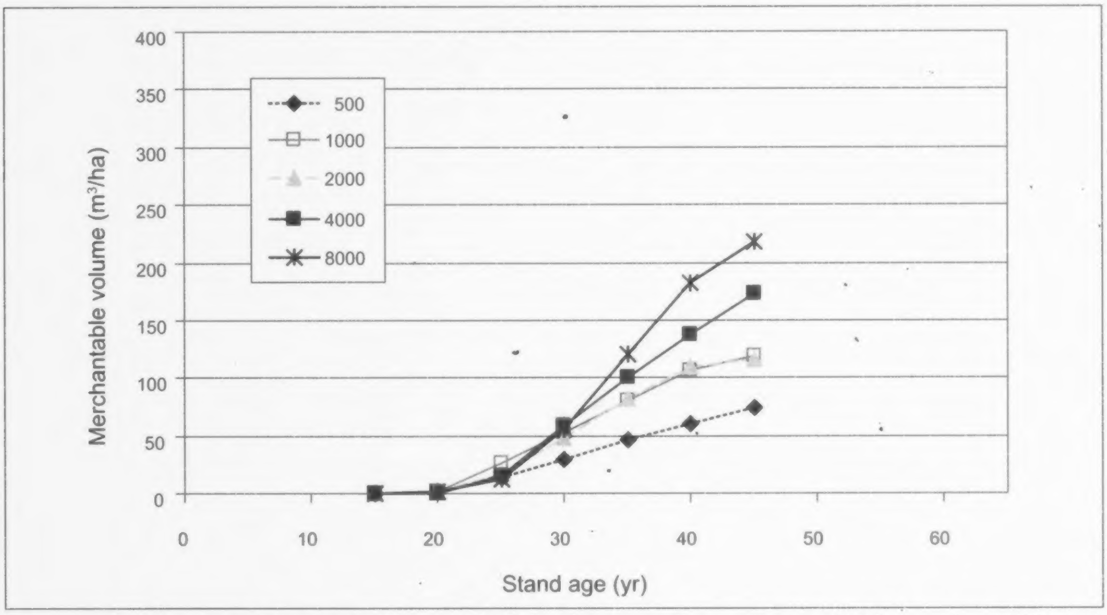

Figure 67. **Merchantable volume (13/7 standard) development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

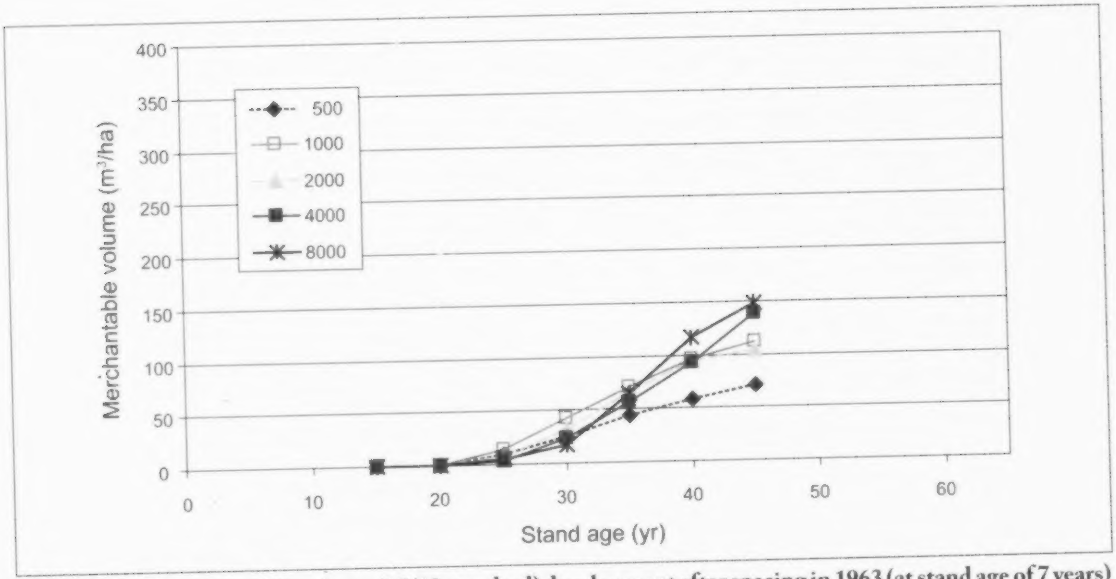

Figure 68. **Merchantable volume (15/10 standard) development after spacing in 1963 (at stand age of 7 years) at the Gregg Burn (1963) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

Gregg Burn Juvenile Spacing Experiment, Project NOR-402 (1984)

Establishment and Objectives

The Gregg Burn 1984 spacing experiment, established by V.S. Kolabinski and S. Lux of the Canadian Forestry Service, was a follow-up to the original 1963 experiment. The two experiments had similar spacing treatments but were performed at different stand ages (7 and 28 years). The experimental sites are located in the Upper Foothills section (B.19c) of the Boreal Forest Region (Rowe 1972), about 40 km south of Hinton, Alberta. The medium productivity plots for the 1984 experiment were established immediately adjacent to the medium productivity plots for the 1963 experiment. The high and low productivity plots for the 1984 experiment were established a few kilometres south and west of the medium productivity site. The objective was to obtain information on stand development following precommercial thinning at a stand age of 28 years.

Experimental Design and Treatments

As for the 1963 installation, the 1984 installation consisted of three different sites, classified by productivity (high, medium, and low); with two replicate blocks of treatments at each site. On the basis of the early results of the 1963 experiment, the number of spacing treatments in the 1984 installation was reduced to four, with the two extreme spacing treatments from 1963 eliminated and one intermediate spacing treatment added. The three spacing treatments repeated from the Gregg 1963 experiment were 1000, 2000, and 4000 stems per hectare, and the added spacing level was 1.83 m or approximately 3000 stems per hectare. Measurements were made in 1984, 1989, 1996, and 2004. Control plots were established in adjacent unthinned parts of the stand in 2004.

Gregg Burn 1984 Spacing Experiment—Low Productivity Site

Location and Access

To access the Gregg Burn (1984) low productivity site (53°10.3'N, 117°18.3'W, legal location 28-48-23-W5) from Hinton, follow these directions:

Travel west on Highway 16 to the junction with Highway 40.

Turn left (south) on Highway 40 and travel 22.8 km to the Gregg River Road.

Turn left (east) on the Gregg River Road and travel 8.2 km to the Tri-Creeks Road.

Turn right (south) on the Tri-Creeks Road and travel 10.2 km.

Turn right (west) on a small unmarked road and travel 0.5 km.

Look for blue boundary marking for the trial site on the left.

Site Description

The low productivity site is located in the Upper Foothills ecological subregion of west-central Alberta on a gentle southeast aspect slope (3–5% grade). Soils are clayey, with strong mottling. The ecological soil moisture regime is mesic with a fluctuating water table, and the nutrient regime is poor (Ecotope Consulting Services 1999). The site was classified as having a D1.2 lodgepole pine-black spruce/Labrador tea/feather moss plant community.

Results after 20 Years

Tree Growth and Mortality

The cumulative mortality among all treatments was low to moderate, remaining below 12% over the 20-year period (Fig. 69). Mortality was highest immediately after treatment and then decreased with time. Unlike the situation in the

1963 experiment, there did not appear to be a consistent relationship between mortality and spacing treatment for thinning performed at a stand age of 28 years. Unexpectedly, the highest cumulative mortality occurred in the treatment with 2000 stems per hectare (11.5% over the 20-year period).

Diameter growth slowly diverged among the treatments (Fig. 70). After 20 years, there was an observable trend of increased diameter growth with increased spacing; however, there was no difference between the treatments with 2000 and 3000 stems per hectare. The differences among treatments were very small, and the total range in average diameter was just over 2 cm. The average diameter of trees in the control plots (less than 4 cm) was much smaller than in all the treatment plots.

There did not appear to be any significant difference among the treatments in terms of height growth (Fig. 71). Even after 20 years, the average heights in all 4 spacing treatments were within 1 m of each other. However, heights in the control plots were approximately 1 m less than those in the treated plots.

Stand Development

Stand density was virtually unchanged over the 20-year measurement period in the treatments with 1000 and 3000 stems per hectare (Fig. 72), neither of which experienced significant mortality or ingrowth. The other two treatments experienced a small amount of mortality and some noticeable ingrowth in the most recent measurement interval. Density in the control plots was an order of magnitude greater than in the thinned plots.

The diameter-class distributions among the spacing treatments were similar. The three widest spacings had the same modal diameter class (8 cm) and differed mostly in the dispersion of their distributions (Fig. 73). The diameter distribution for the treatment with 4000 stems per hectare was shifted left (toward smaller diameter), and that for the control plots was shifted even farther left. The control plots had a large variation in diameters; however, they also had a much higher frequency of trees with very small diameters than any of the treated plots.

Height–diameter relationships revealed a difference of less than 1 m in height for a given diameter class among the treatments (excluding control). The difference in height–diameter curves between the control and the other treatments increased with diameter, to a difference of over 3 m in height for the 11-cm diameter class (Fig. 74).

Stand basal area increased consistently with increasing density (Fig. 75). At stand age 48 years, the highest density treatment (4000 stems per hectare) had the greatest basal area per hectare (18.1 m^2/ha), almost three times that of the treatment with 1000 stems per hectare (6.6 m^2/ha). The basal area of the unthinned treatment was greater still (37.7 m^2/ha). After 20 years, the residual trees had still not completely reclaimed the growing space freed up by the spacing treatments. Total volume followed the same trends as basal area (Fig. 76). Individual tree growth differences were modest at this site, where basal area and volume were strongly influenced by the number of trees per hectare. The sites with the greatest total volume were those with the highest stem densities. The control sites, with 145 m^3/ha, had more than double the total volume of the treatment with 4000 stems per hectare (61 m^3/ha), which in turn had more double the total volume of the treatment with 1000 stems per hectare (21.5 m^3/ha).

Trees in these plots were just beginning to come to merchantable size at the time of the most recent measurement (Figs. 77 and 78). To date, it appears that the intermediate spacing treatments (2000 and 3000 stems per hectare) have produced the most merchantable wood, while the extreme spacing treatments (1000 and 4000 stems per hectare) have yielded the least. However, it is still too early to draw conclusions.

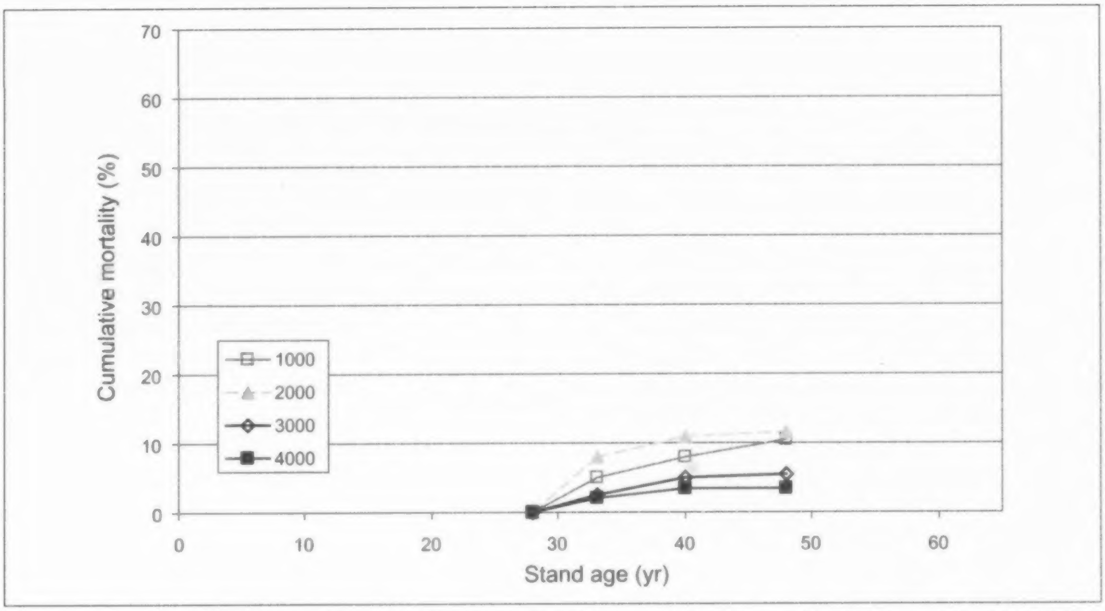

Figure 69. **Cumulative mortality after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

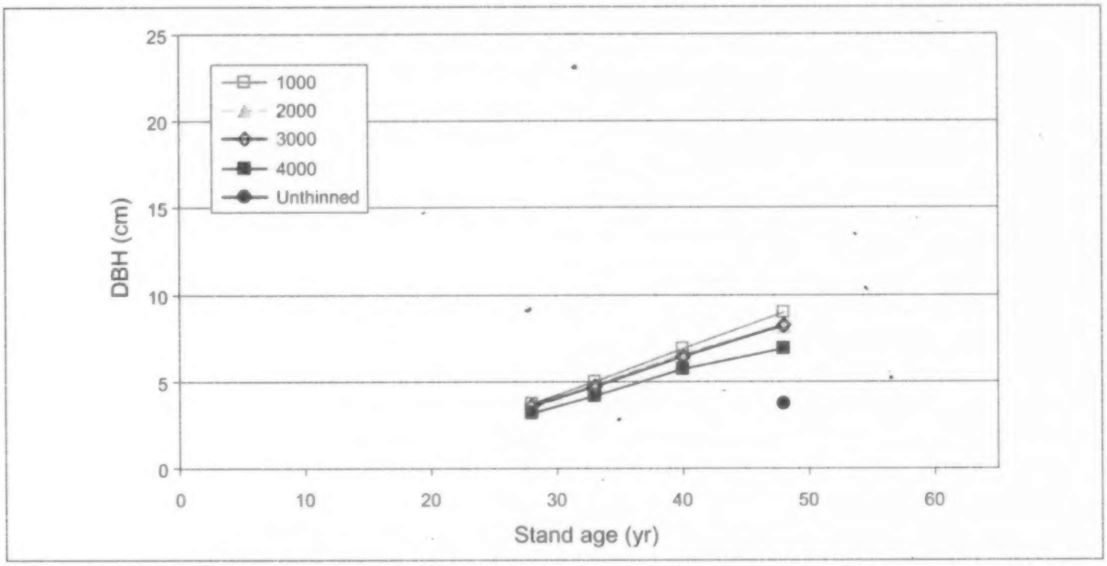

Figure 70. **Diameter growth after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

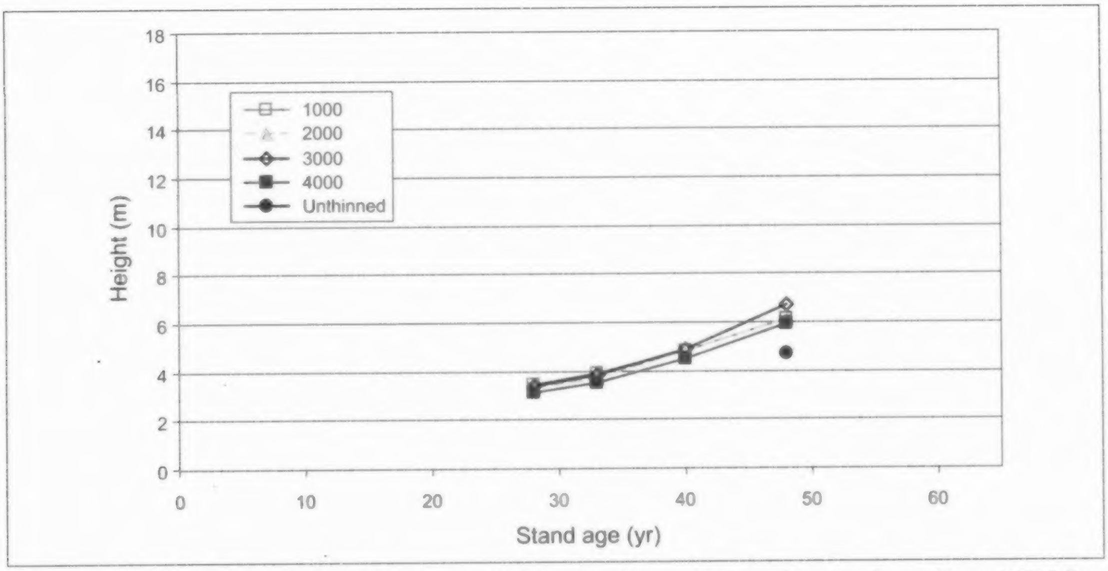

Figure 71. **Height growth after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

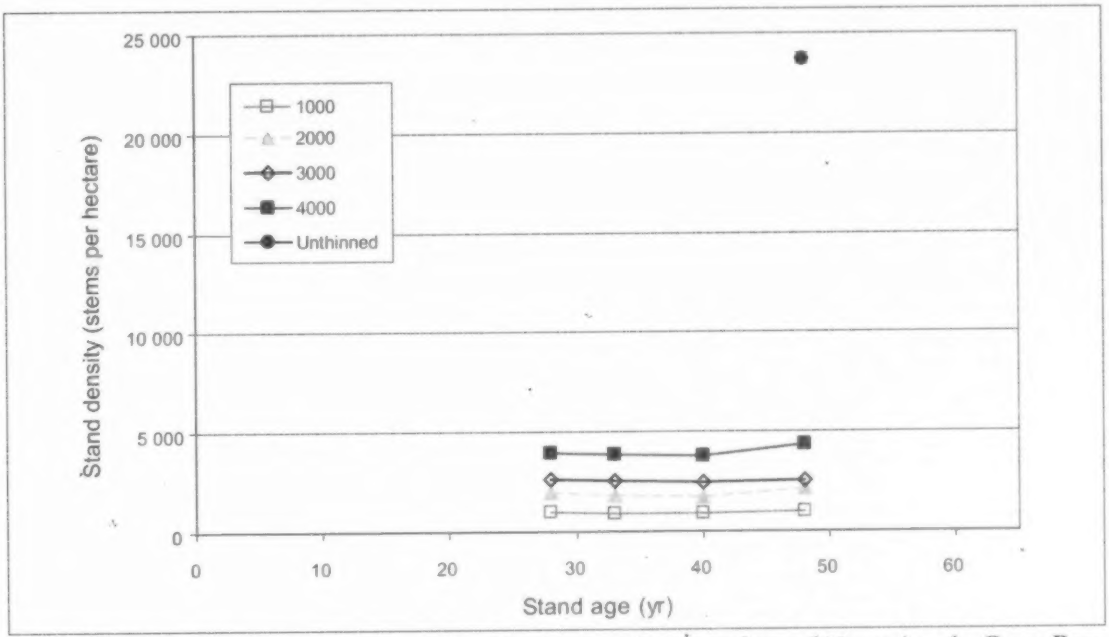

Figure 72. **Stand density development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

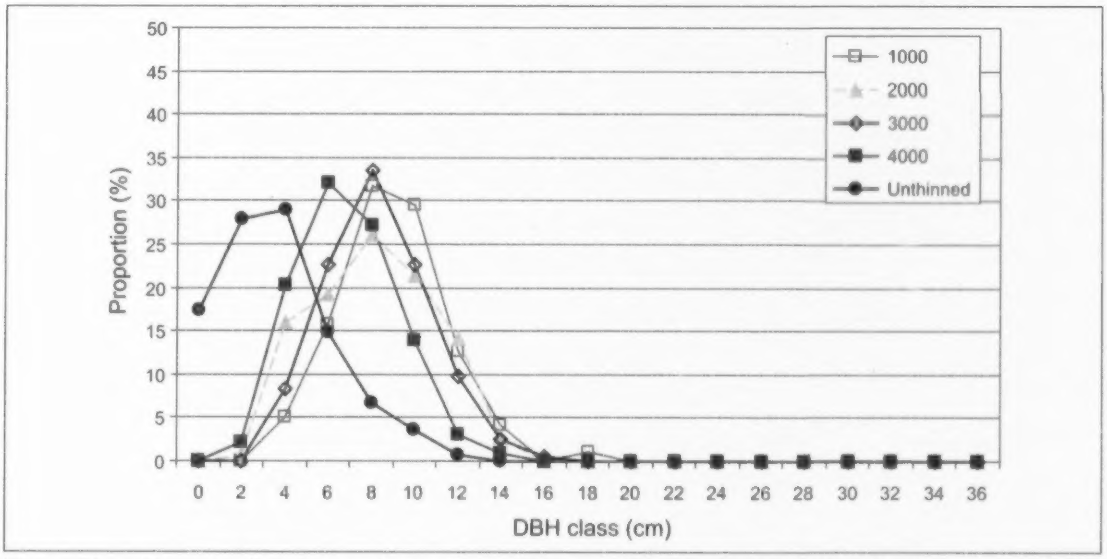

Figure 73. **Diameter distribution, by treatment, 20 years after thinning in 1984 at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

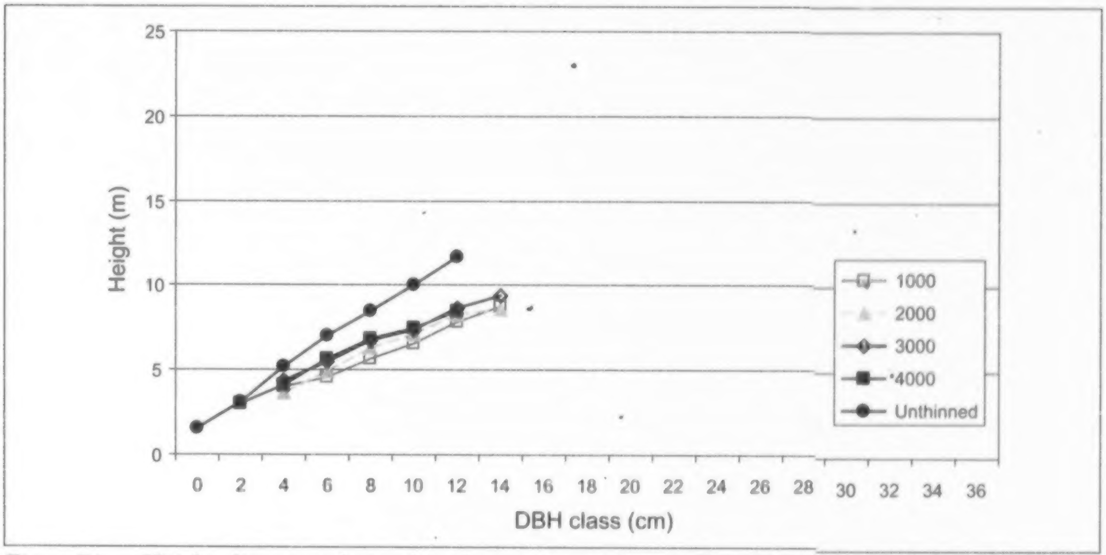

Figure 74. **Height–diameter relationships, by treatment, 20 years after thinning in 1984 at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

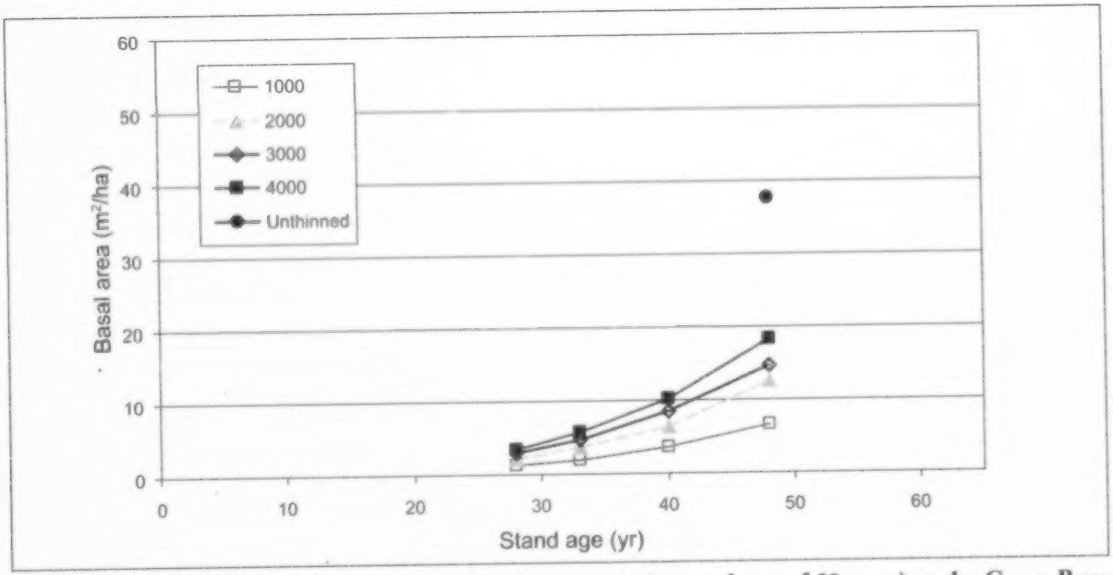

Figure 75. **Basal area development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

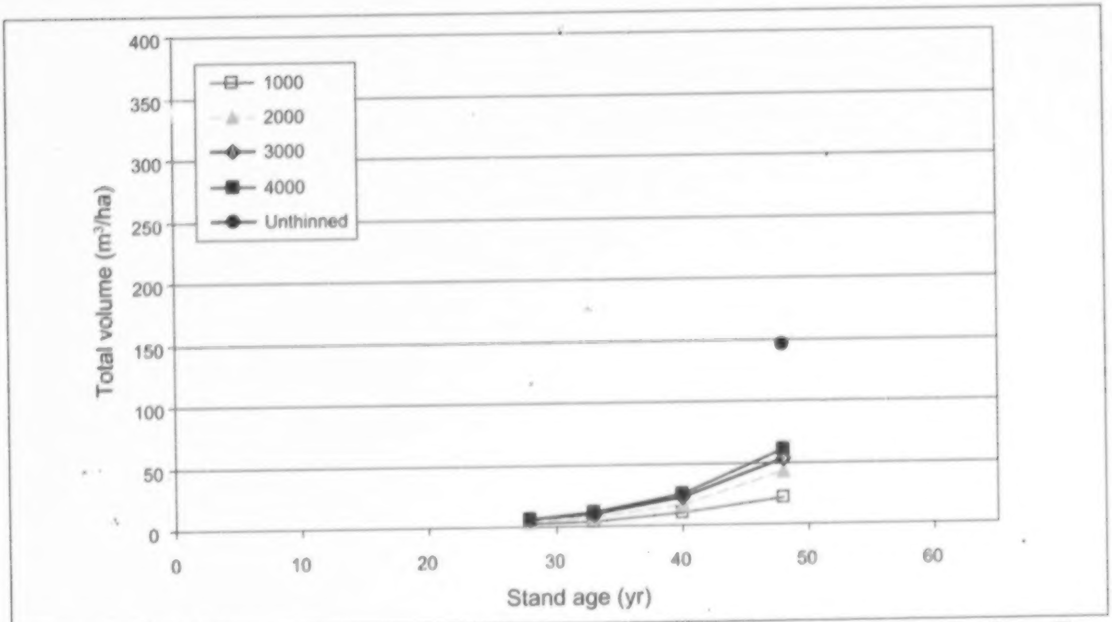

Figure 76. **Total volume development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

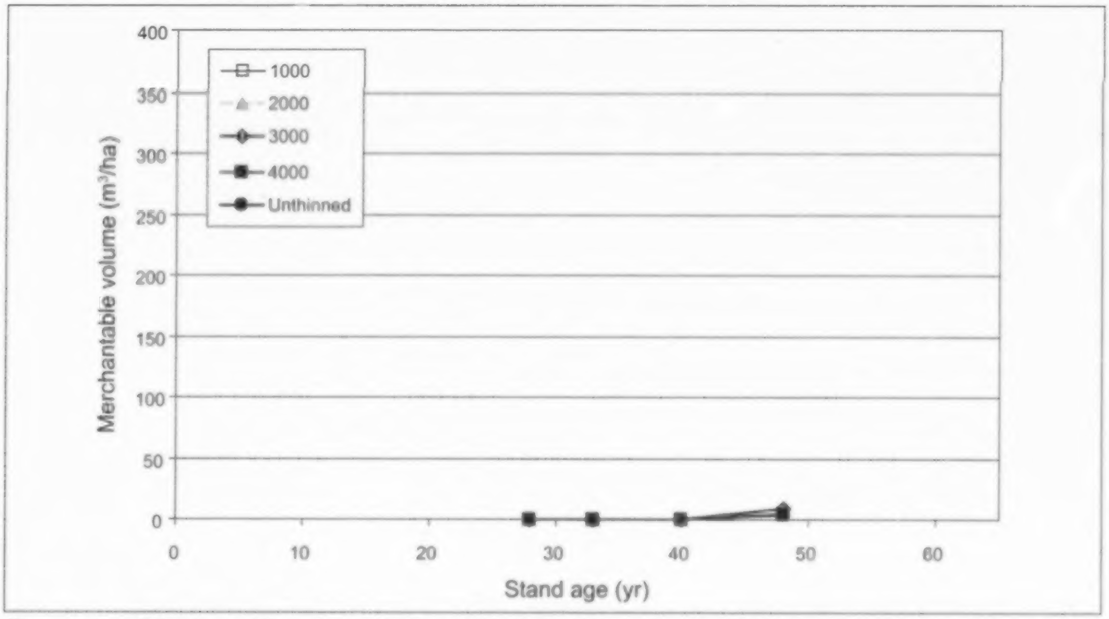

Figure 77. **Merchantable volume (13/7 standard) development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

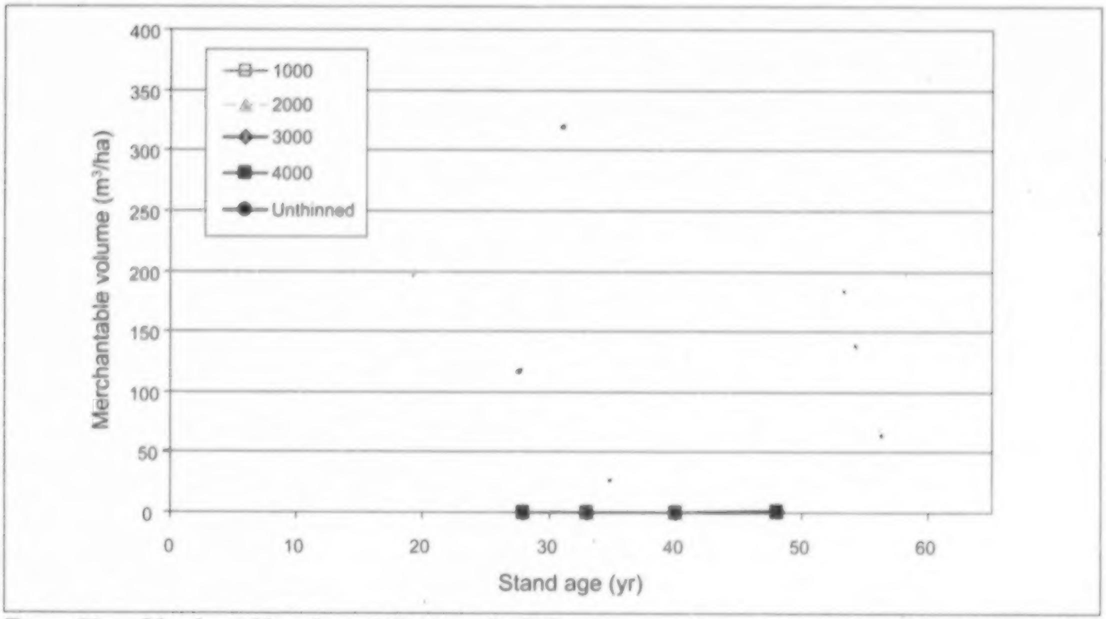

Figure 78. **Merchantable volume (15/10 standard) development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) low productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

Gregg Burn 1984 Spacing Experiment—Medium Productivity Site

Location and Access

To access the Gregg Burn (1984) medium productivity sites (53°13.6'N, 117°21.1'W, legal location 6/7/11-18-49-23 W5) from Hinton, follow these directions:

Travel west on Highway 16 to the junction with Highway 40.

Turn left (south) on Highway 40 and travel 22.8 km to the Gregg River Road.

Turn left (east) on the Gregg River Road and travel 8.2 km to the Tri-Creeks Road.

Turn right (south) on the Tri-Creeks Road and travel 2.8 km.

Watch for signage for the first replicate block on the left.

To reach the second replicate, travel 200 m farther south down the road.

Turn left (east) and cross the clearing to the trail in the southeast corner.

The sign for the block is 290 m from the road.

Site Description

The medium productivity sites are located in the Upper Foothills ecological subregion of west-central Alberta on south to southwest aspect midslopes, with grade varying from 5% to 25%. Soils are clay loams with some overlying sandy loams. The ecological soil moisture regime is mesic, and the nutrient regime is poor to medium (Ecotope Consulting Services 1999). Replicate 1 (with a poor nutrient regime) was classified as having a D1.2 lodgepole pine-black spruce/Labrador tea/feather moss plant community; plots 1, 2, and 3 of replicate 2 (medium nutrient regime) were classified as having a C1.1 lodgepole pine/Canada buffalo-berry/hairy wild rye plant community; and the remaining plots in replicate 2 were classified as having an E1.3 lodgepole pine/Labrador tea/feather moss plant community.

Results after 20 Years

Mortality was low in all treatments, 1% or less annually over the 20-year measurement period (Fig. 79). There did not appear to be any consistent relationship between mortality and spacing treatment this early in post-treatment stand development, although the highest density treatment (4000 stems per hectare) had the highest cumulative mortality.

As expected, average diameter growth increased with spacing (Fig. 80). The difference in diameter growth between the two least dense treatments increased over time. The trees in the control plots had an average diameter of less than 6 cm, about half the smallest average diameter of trees in the treated plots.

There was essentially no difference in height growth among the spacing treatments at this site (Fig. 81). Twenty years after treatment, the difference between the tallest and shortest average height in the treated stands was less than 0.5 m. In 2004, the trees in the spaced plots were, on average, 4 m taller than those in the control plots.

Stand Development

Stand density declined only slightly over time in the treatment with 4000 stems per hectare and negligibly in the other treatments (Fig. 82). The control plots maintained high densities; however, these were still about 10 000 stems per hectare lower than densities at the low productivity site.

As at the low productivity site, the diameter distributions of the spacing treatments overlapped considerably (Fig. 83). The most notable differences were that the curve for the treatment with 1000 stems per hectare was shifted slightly farther to the right of the other curves, and the curve for the control plots was shifted left. Growth in the control plots at this site was better than at the low productivity site. Also, the average diameter had a nearly normal distribution at the medium productivity site, rather than the truncated distribution curve observed at the low productivity site. Trees in the various treatments appeared to follow the same height–diameter trajectory, with the exception of the treatment with 1000 stems per hectare, which contained shorter trees for a given diameter class (Fig. 84). This was a result of the wider spacing allowing for greater diameter growth than in the other spacings, while height growth was unaffected.

As expected, stand basal area increased with stand density (Fig. 85). The curves for treatments with 2000 and 3000 stems per hectare converged over time, such that these treatment plots eventually had the same basal area. In 2004, the treatment with the highest stand density (4000 stems per hectare) had the highest basal area among the spacing treatments, just under 30 m^2/ha; this was about equal to the basal area in the control plots, despite the fact that tree diameters in the control plots were much smaller than those in the treated stands.

Total volumes followed trends similar to those for basal area (Fig. 86). The highest density treatment (4000 stems per hectare) had more than double the total volume per hectare in the least dense treatment (1000 stems per hectare) (185 and 87 m^3/ha, respectively). In 2004, the control plots had a total volume equal to that of the treatment with 3000 stems per hectare (150 m^3/ha) and only slightly greater than that of the treatment with 2000 stems per hectare (141 m^3/ha).

Unlike the plots at the low productivity site, these stands have been accumulating merchantable volume for 10 years (Figs. 87 and 88). At the 13/7 standard, the treatment with 2000 stems per hectare has maintained the highest volume, but by 2004, the total volume for the treatment with 4000 stems per hectare had increased to a level greater than all but the 2000 stem per hectare treatment. In 2004, the treatment with 3000 stems per hectare had surpassed the treatment with 1000 stems per hectare in terms of 13/7 merchantable volume. The lowest density treatment (1000 stems per hectare) had the least merchantable volume and the smallest increase in merchantable volume during the most recent measurement interval. The greater number of stems remaining on the higher density treatments appeared to make a greater contribution to the merchantable volume than did the added volume from the larger, faster-growing trees in the lower density treatments. At the 15/10 standard, the faster-growing trees in plots with wider spacing were still producing the greatest amount of merchantable volume.

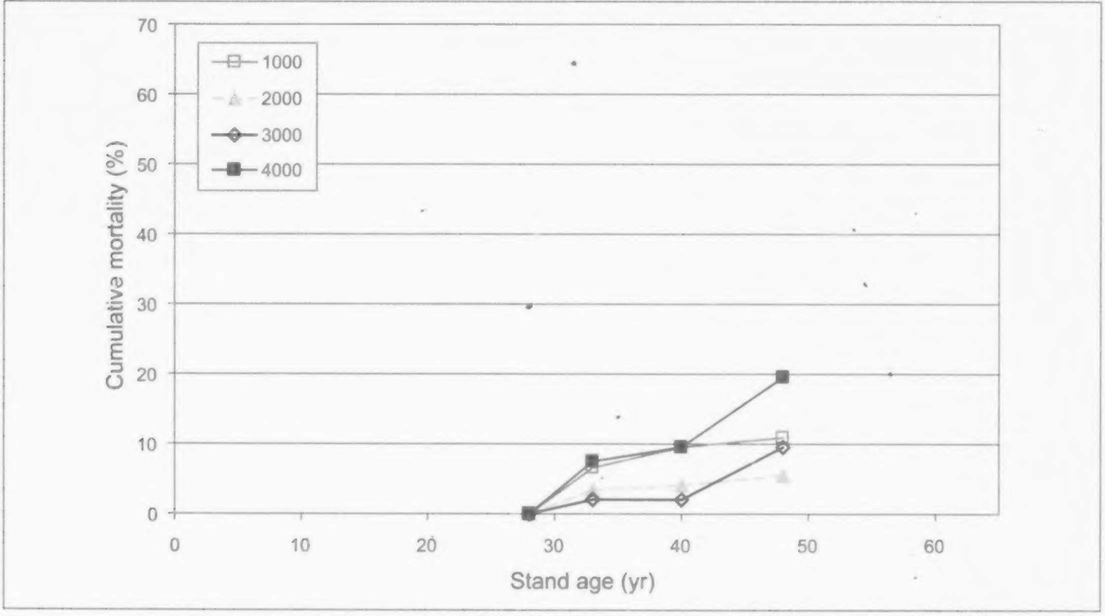

Figure 79. **Cumulative mortality after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

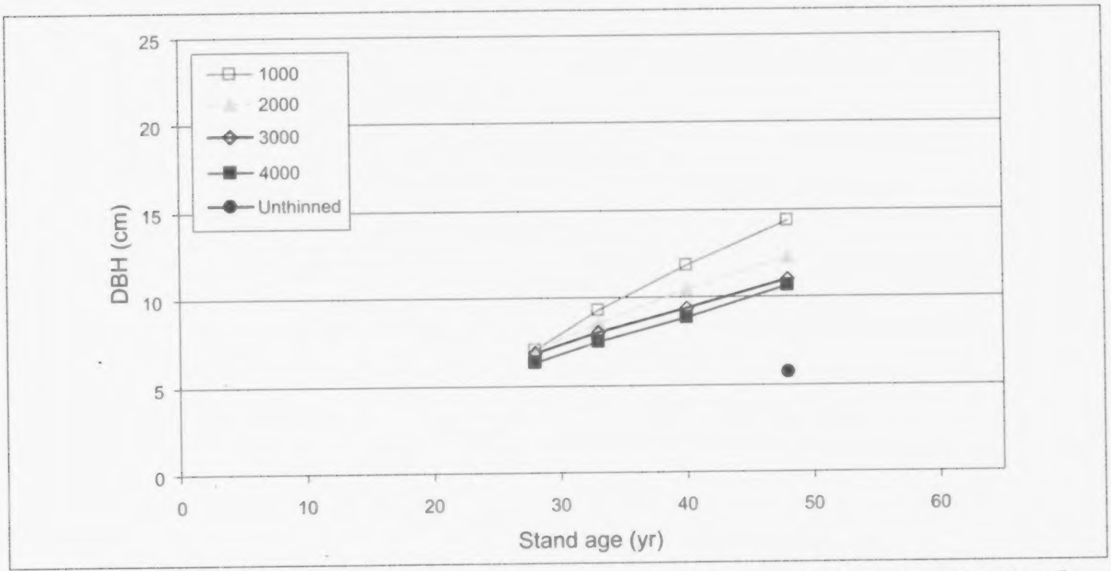

Figure 80. **Diameter growth after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

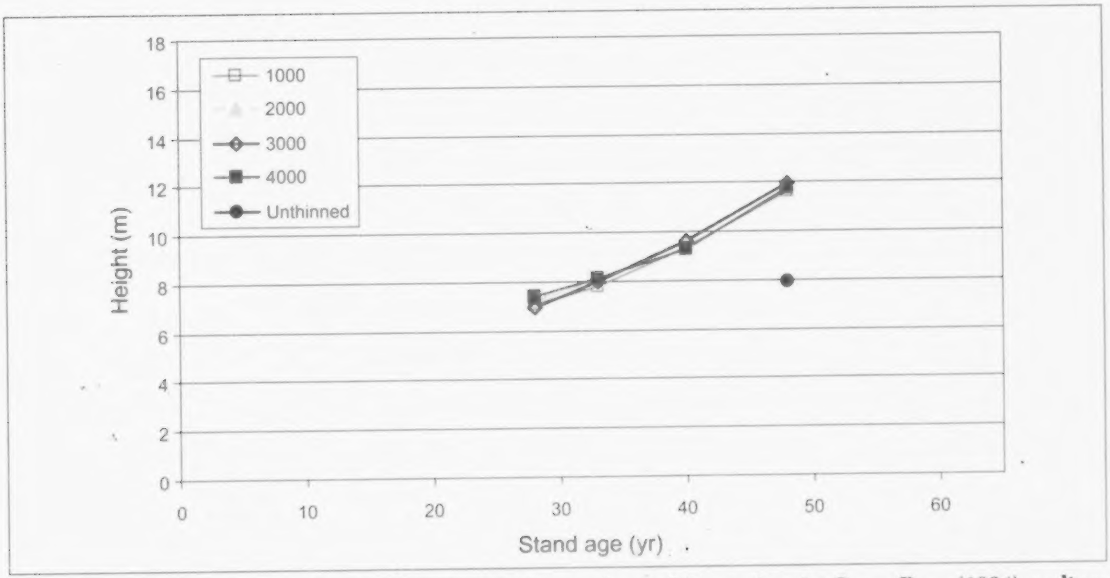

Figure 81. **Height growth after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

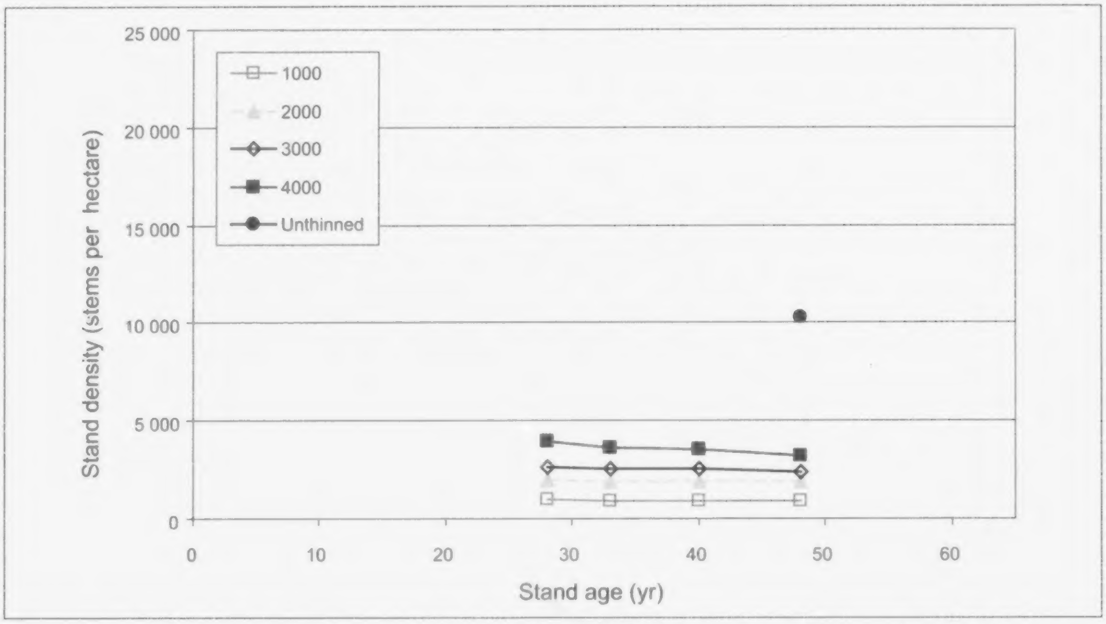

Figure 82. **Stand density development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

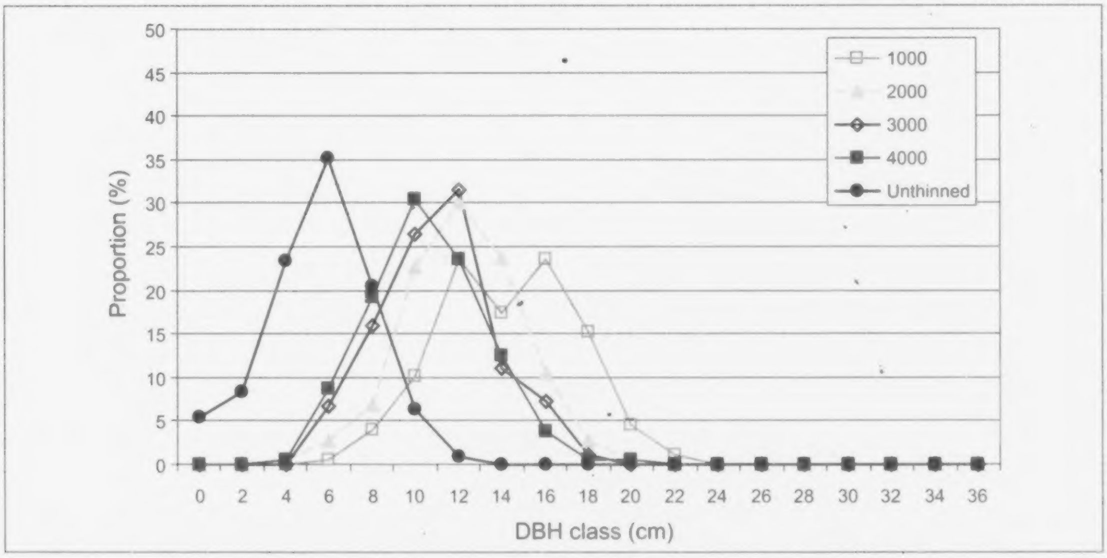

Figure 83. **Diameter distribution, by treatment, 20 years after thinning in 1984 at the Gregg Burn (1984) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

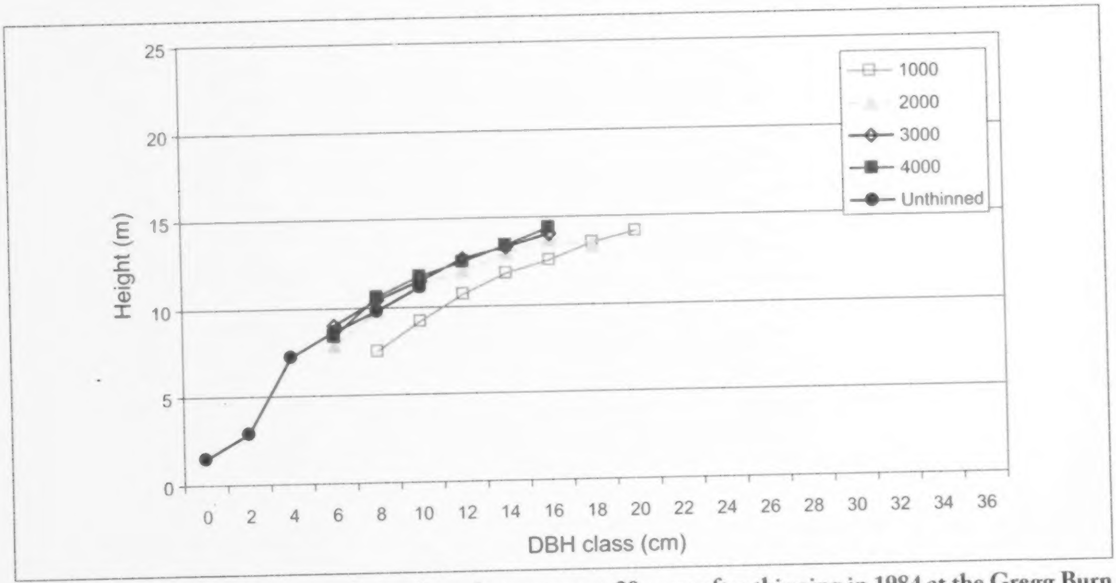

Figure 84. Height–diameter relationships, by treatment, 20 years after thinning in 1984 at the Gregg Burn (1984) medium productivity site. Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

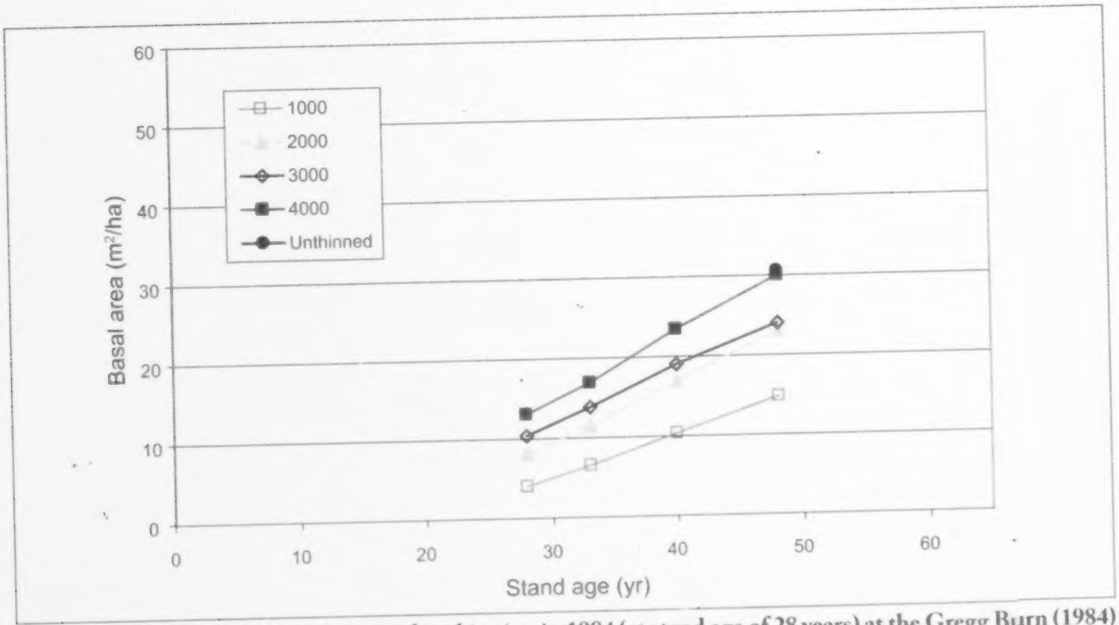

Figure 85. Basal area development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) medium productivity site. Treatments are designated by stand density after thinning (stems per hectare).

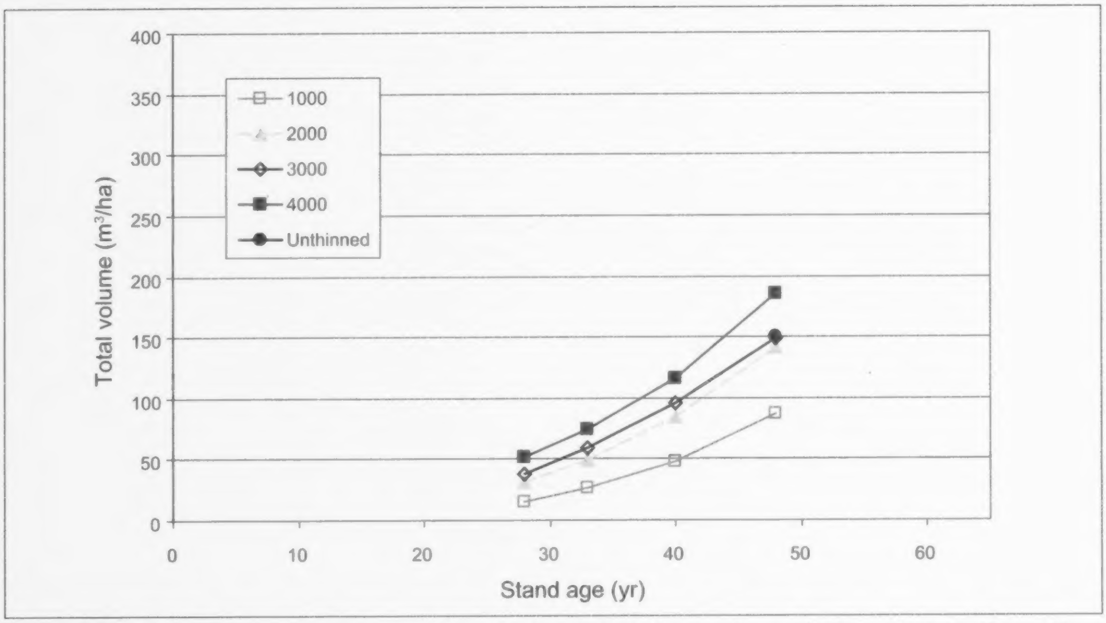

Figure 86. **Total volume development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

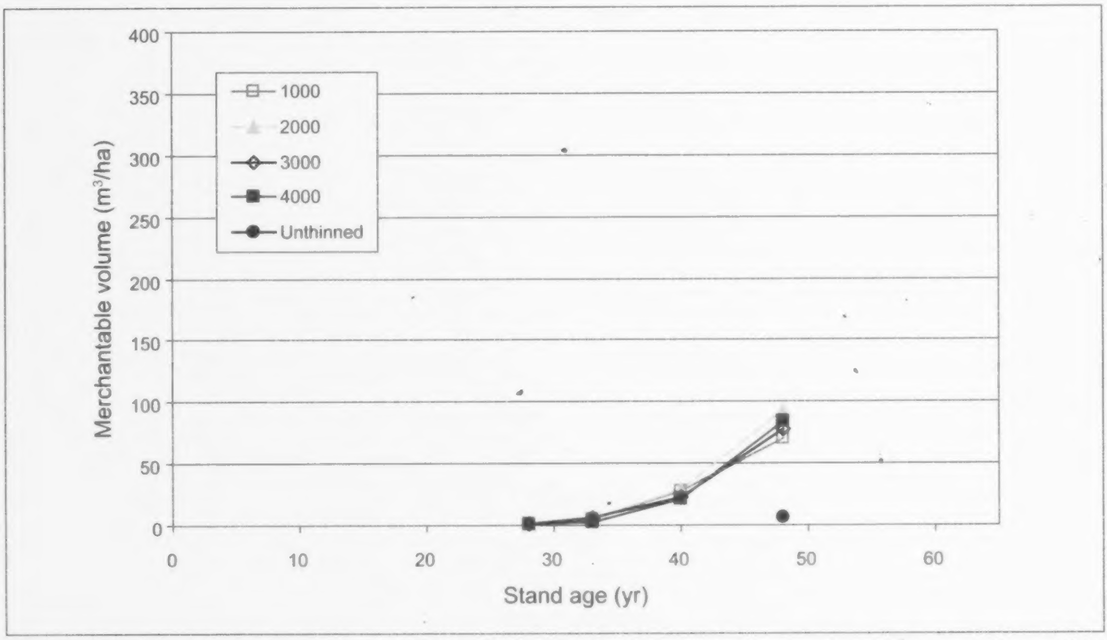

Figure 87. **Merchantable volume (13/7 standard) development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

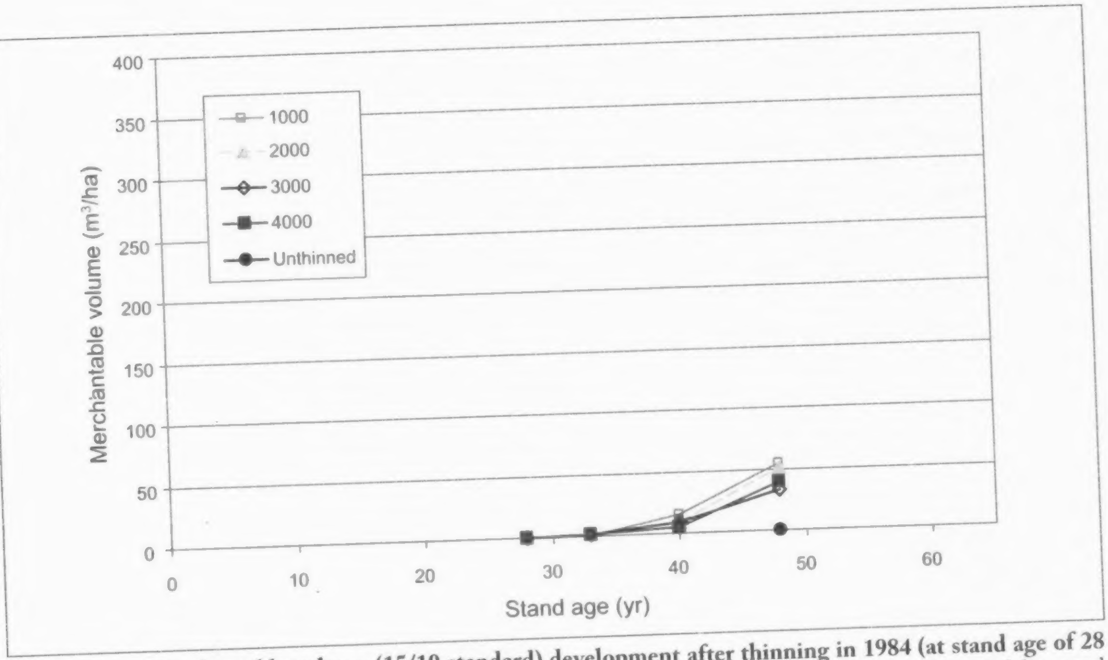

Figure 88. **Merchantable volume (15/10 standard) development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) medium productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

Gregg Burn 1984 Spacing Experiment—High Productivity Site

Location and Access

To access the Gregg Burn (1984) high productivity site (53°09.6'N, 117°20.1'W, legal location 12/13-20-48-23-W5) from Hinton, follow these directions:

Travel west on Highway 16 to the junction with Highway 40.

Turn left (south) on Highway 40 and travel 22.8 km to the Gregg River Road.

Turn left (east) on the Gregg River Road and travel 8.2 km to the Tri-Creeks Road.

Turn right (south) on the Tri-Creeks Road and travel 10.2 km.

Turn right (west) on a small unmarked road and travel 2.8 km.

Look for blue boundary paint and a sign for the trial site on the right.

Site Description

The high productivity site is located in the Upper Foothills ecological subregion of west-central Alberta on a flat to moderate slope (0–10% grade) with a southeast aspect. Soil textures are silty loam to sandy clay. The ecological soil moisture regime is mesic (with the exception of the treatment with 1000 stems per hectare, replicate 2, plot 13, which was wetter), and the nutrient regime is medium. The site was classified as having an E1.3 lodgepole pine/Labrador tea/ feather moss plant community.

Results after 20 Years

Tree Growth and Mortality

The mortality among all treatments was low, at or below 1% annually, except for the treatment with 4000 stems per hectare, for which cumulative mortality tripled, from 5.5% to 17%, over the most recent measurement period (Fig. 89). Although at the time of the most recent measurement mortality was greatest for the highest density treatment and lowest for the lowest density treatment, the relationship of mortality to density was not consistent over time.

Diameter growth trajectories were parallel for all but the widest spacing treatment, i.e., differences in average diameter between treatments that existed at the first measurement were maintained over time (Fig. 90). However, for the treatment with 1000 stems per hectare, diameters increased at a greater rate than in the other treatments. In 2004, trees in the control plots had an average diameter of less than 6 cm, about half the average diameter seen in the treated plots with the smallest diameters.

Height growth trajectories were also parallel for all of the spacing treatments at this high productivity site (Fig. 91). Twenty years after treatment, the difference between the tallest and shortest average height in the treated plots was less than 2 m, identical to the difference in 1984. Average heights in the treated plots were more than 3 m greater than in the control plots.

Stand Development

- Stand density declined slightly over time in the treatment with 4000 stems per hectare and negligibly in the other treatments (Fig. 92). The control plots maintained high densities; however, these were still about 12 000 stems per hectare lower than at the low productivity site, but about 2000 stems per hectare higher than at the medium productivity site.

The diameter distributions for the treatments with 3000 and 4000 stems per hectare were similar, as were those for the treatments with 1000 and 2000 stems per hectare, these two pairs of curves being slightly offset from each other (Fig. 93). For the control plots, however, the diameter distribution was shifted significantly toward the smaller diameter classes.

Height–diameter relationships were the same as at the medium productivity site: all of the treatments followed the same trajectory, except for the treatment with 1000 stems per hectare, where trees were about 2 m shorter in a given diameter class (Fig. 94).

Stand basal area was highest for the highest density treatment and lowest for the lowest density treatment; the treatments with 2000 and 3000 stems per hectare had the same basal area throughout the measurement period (Fig. 95). Stand density appeared to be the major determinant of basal area, as illustrated by the basal area for control plots, which was more than double that for the treatment with 1000 stems per hectare treatment and 6 m^2/ha greater than the treatment with 4000 stems per hectare.

Total volumes at the high productivity site followed the same trends as basal area (Fig. 96) and were very similar in trend and magnitude to those at the medium productivity site. In 2004, the control plots had the smallest individual trees but the highest stand density, and thus had total volume similar to that of the treatment with the highest volume (4000 stems per hectare).

Although the total volume in the control plots was the same as or greater than that in any of the treated stands, the much smaller individual tree size in the control plots meant that merchantable volume (13/7 standard) was only two-thirds to one-quarter of merchantable volume in the treated plots (Fig. 97). The treatment with intermediate spacing (2000 stems per hectare) had the highest merchantable volume in 2004. For the treatment with 4000 stems per hectare, merchantable volume appeared to be increasing faster than for the other treated plots and may soon overtake the treatment with 2000 stems per hectare. At the 15/10 standard, merchantable volume was still highest in the treatment with 2000 stems per hectare, but the treatment with 4000 stems per hectare had the lowest merchantable volume among the spacing treatments (Fig. 98). However, all of the treatments were just beginning the phase of rapid increase in merchantable volume, and the relative positions of the treatments will likely change significantly over the next few measurements.

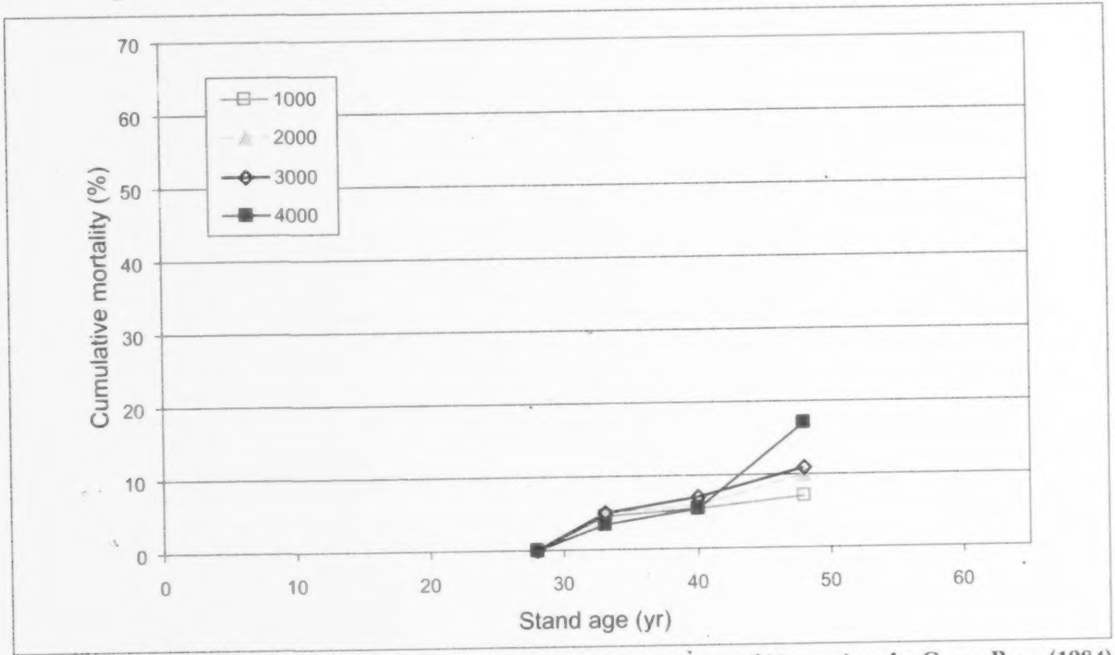

Figure 89. **Cumulative mortality after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

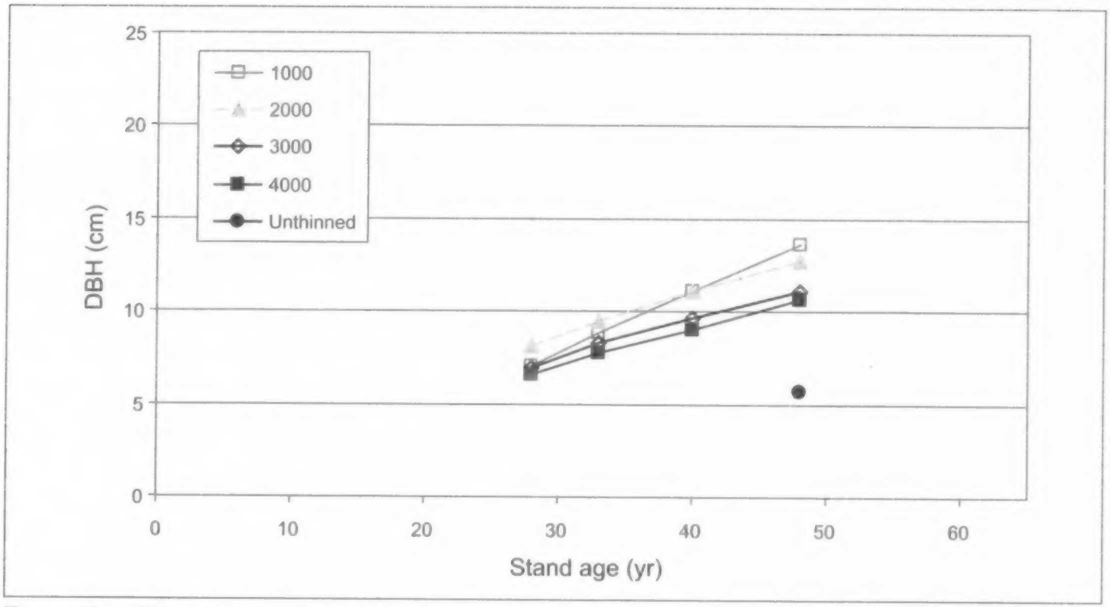

Figure 90. **Diameter growth after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

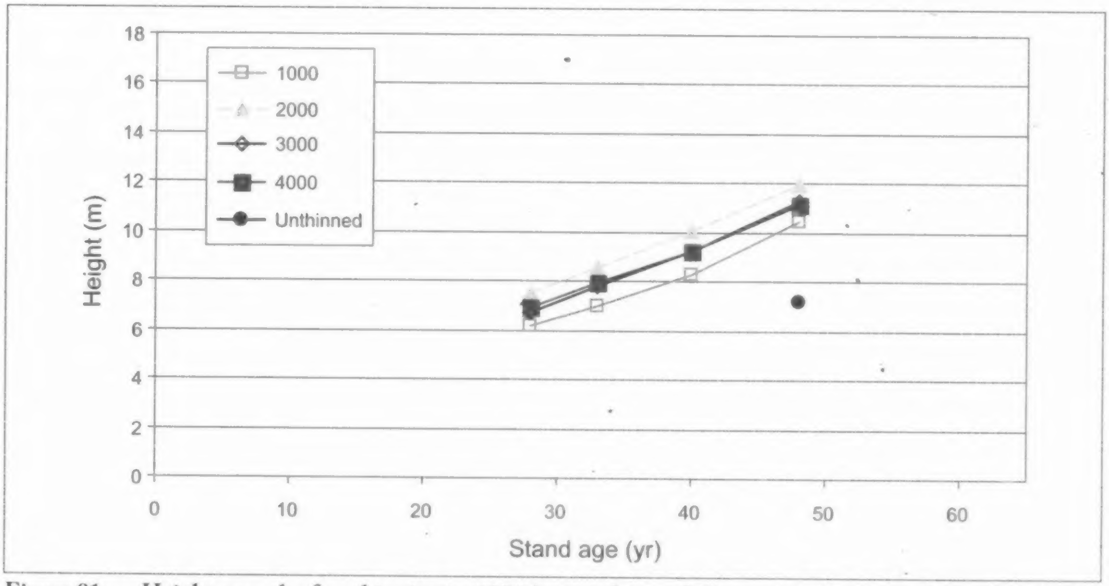

Figure 91. **Height growth after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

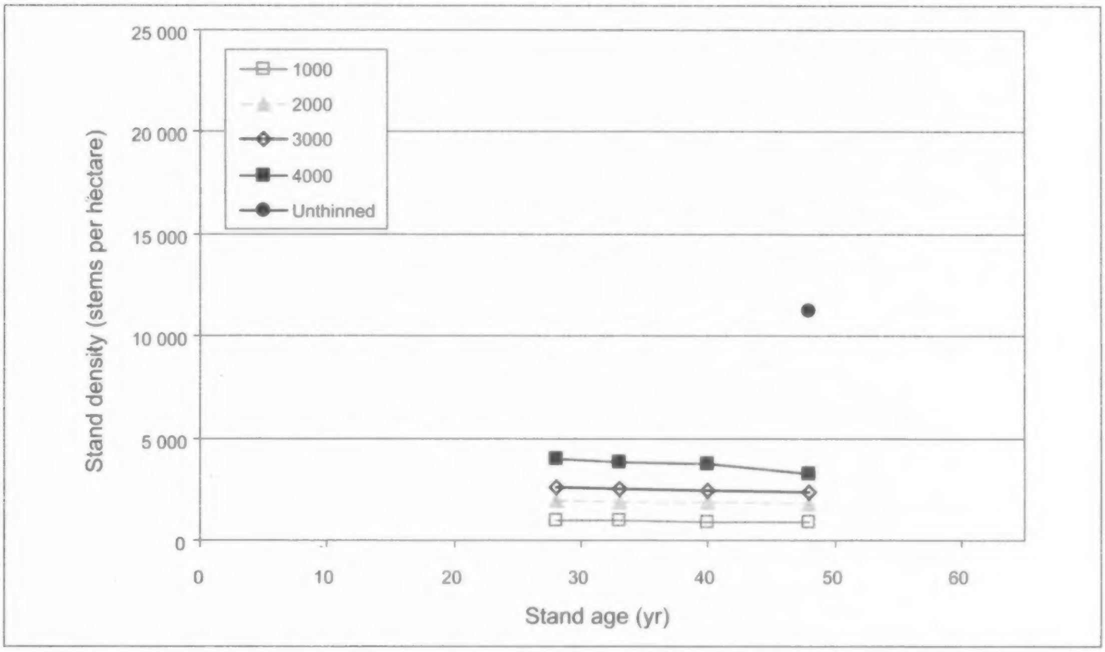

Figure 92. Stand density development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) high productivity site. Treatments are designated by stand density after thinning (stems per hectare).

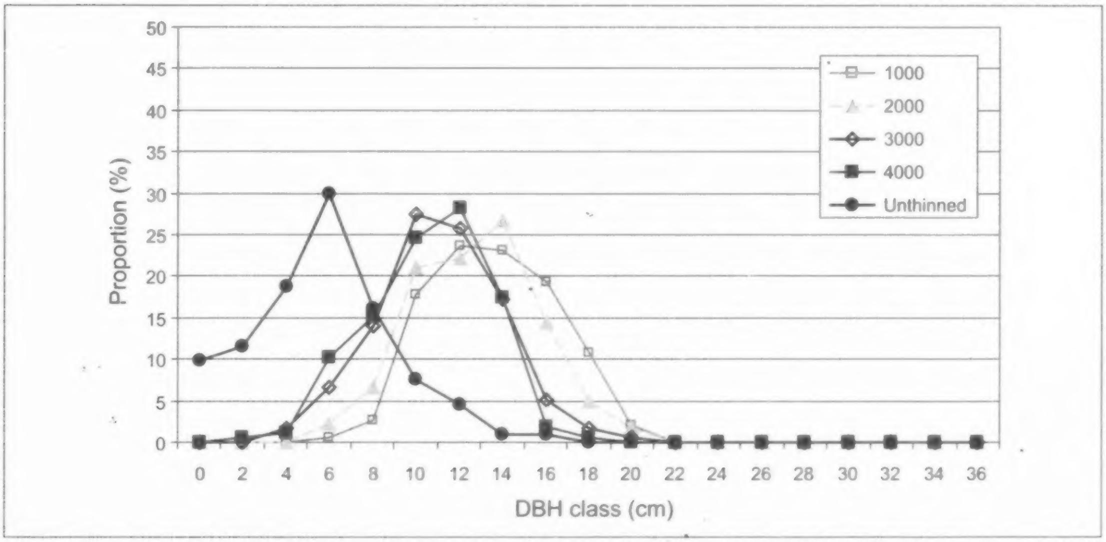

Figure 93. Diameter distribution, by treatment, 20 years after thinning in 1984 at the Gregg Burn (1984) high productivity site. Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

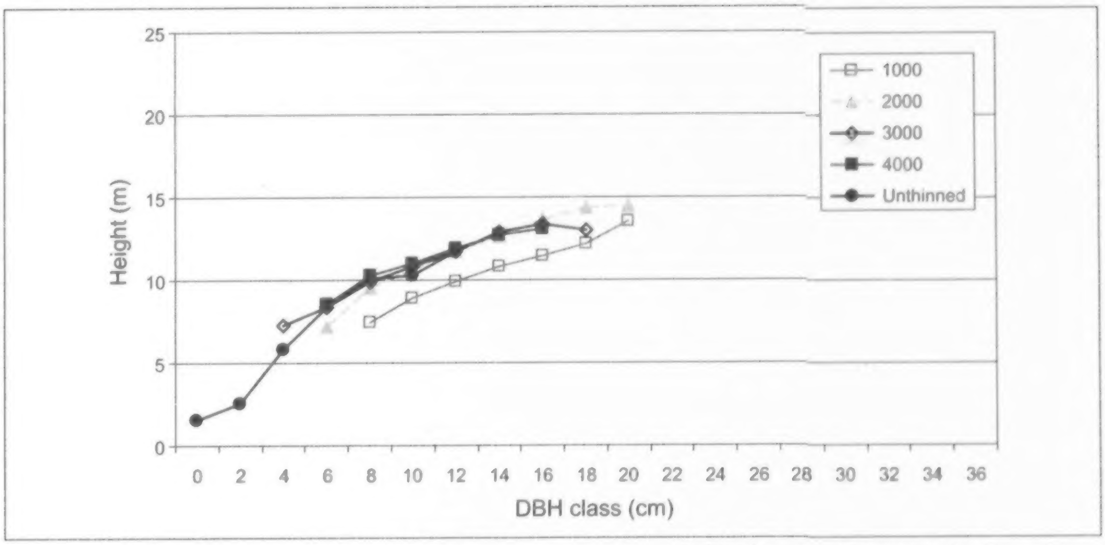

Figure 94. **Height–diameter relationships, by treatment, 20 years after thinning in 1984 at the Gregg Burn (1984) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

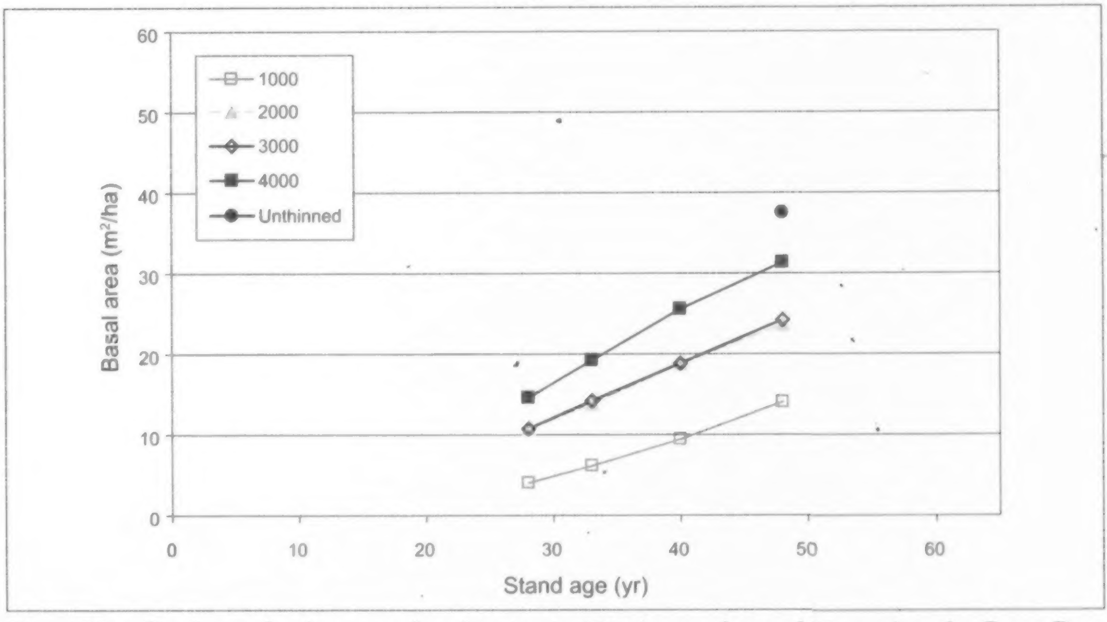

Figure 95. **Basal area development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

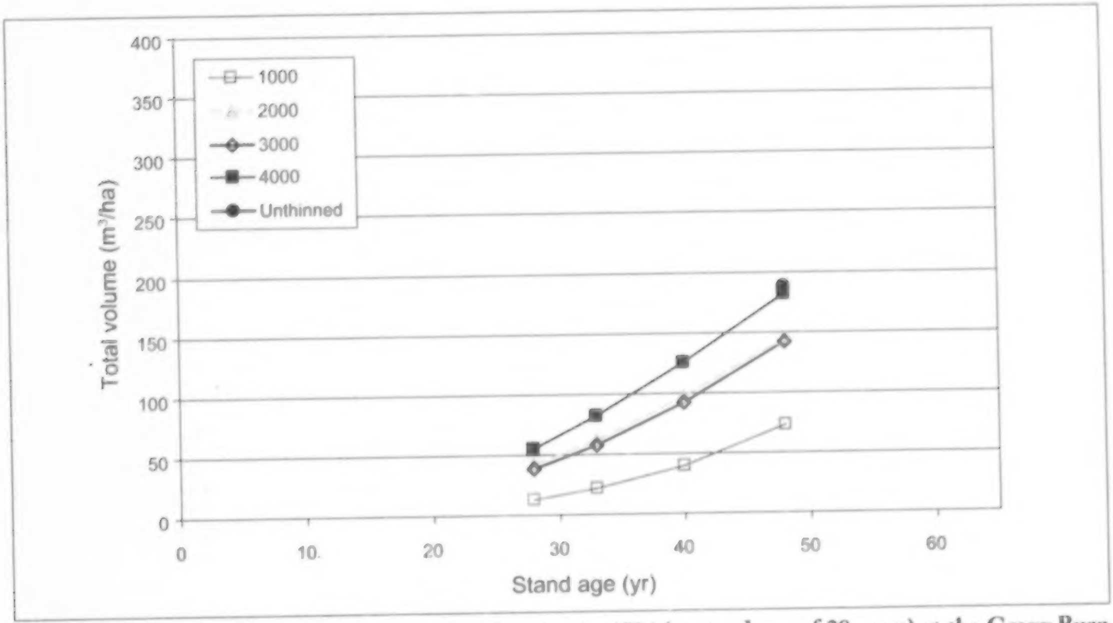

Figure 96. **Total volume development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

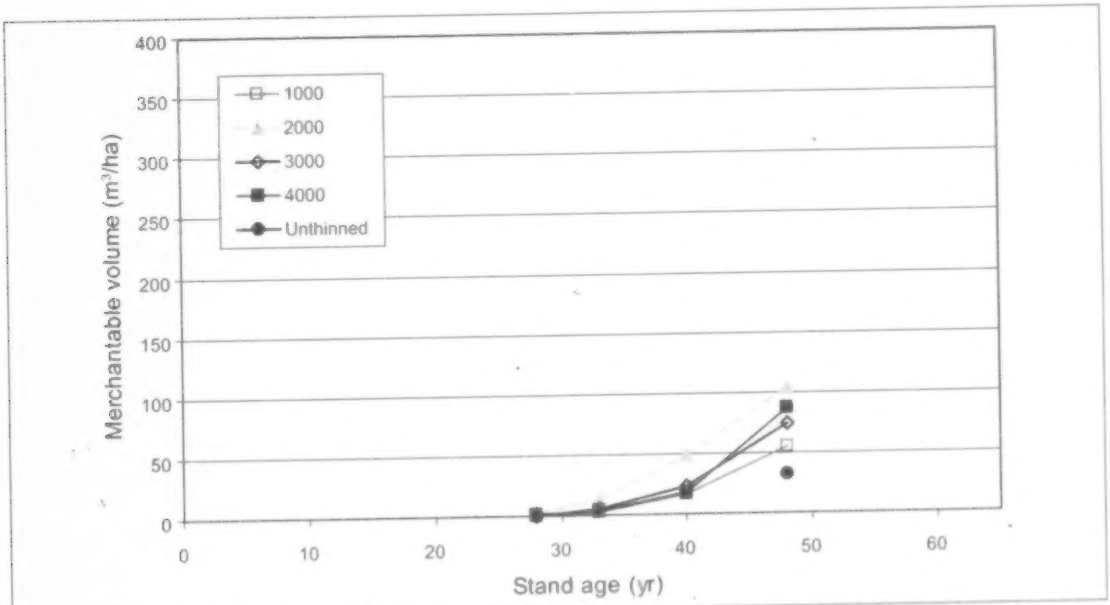

Figure 97. **Merchantable volume (13/7 standard) development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

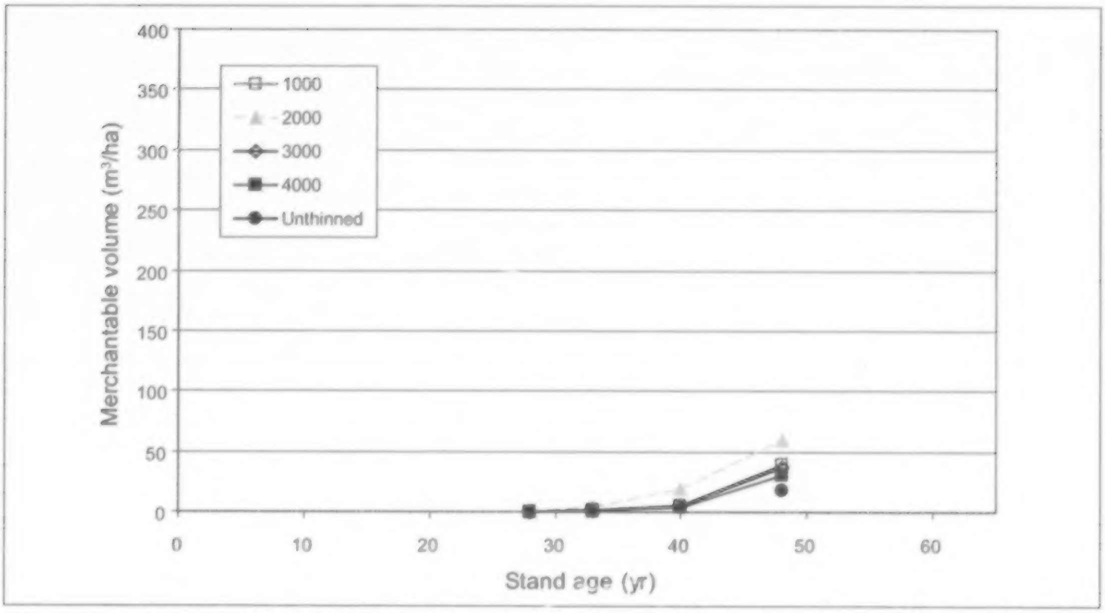

Figure 98. **Merchantable volume (15/10 standard) development after thinning in 1984 (at stand age of 28 years) at the Gregg Burn (1984) high productivity site.** Treatments are designated by stand density after thinning (stems per hectare).

Teepee Pole Creek Spacing Experiment (1967)

Establishment and Objectives

The Teepee Pole spacing experiment was established in 1967 by F. Marsh of the federal Department of Forestry and Rural Development, Forestry Branch, as an extension of project A-100, the Gregg Burn 1963 spacing experiment. The Teepee Pole experiment site is located in the Upper Foothills ecological subregion (near the boundary between the Lower and Upper Foothills subregions) and consists of three separate field sites of differing slope aspect: flat, north-facing, and south-facing. The stands all originated from a 1941 fire, and initial stand densities ranged as high as 250 000 stems per hectare. The objectives of the experiment were to study the effect of spacing on diameter growth, height growth, volume growth, stem form, and wood quality and to determine the age at which different spacings begin to limit tree growth. Results from this experiment have been previously published by Johnstone (1982b) and Yang (1986). Data for the three sites are reported separately here.

Experimental Design and Treatments

The Teepee Pole Creek experiment has a semirandomized complete-block design. At each site, two replicate blocks of treatment plots were installed, using the same procedures and thinning levels as were used in the Gregg Burn (1963) experiment. The treatments were 200, 400, 800, 1600, and 3200 stems per acre, or approximately 500, 1000, 2000, 4000, and 8000 stems per hectare. Plots were sized to contain exactly 100 trees on a uniform square grid. Spacing was done by hand in summer 1967, following a string grid template, with residual trees being located no farther than 46 cm from grid intersections.

All 100 trees in each plot were tagged and their diameter, height, crown length, and crown width measured. Measurements were taken in 1967, 1972, 1977, 1982, 1987, 1992, 1996, and 2003. Most of the data from the 1996 measurements have been excluded because of suspected errors and lack of information about quality control during the collection of data. The data from the control plots, which were installed in that year, have been included. The scales of the graphs are consistent for the three different sites examined here, and they match the scales used for reporting data from the 1963 and 1984 Gregg Burn experiments.

Teepee Pole Creek Spacing Experiment (1967)—Flat Site

Location and Access

The Teepee Pole Creek flat site (51°54.1'N, 115°11.2'W, legal location 8-10-34-9-W5) is located about 55 km southwest of Rocky Mountain House on the bottom of the Teepee Pole Creek valley, just off the Forestry Trunk Road. To access the site from Caroline, follow these directions:

Travel 8 km west on Highway 22, to Highway 591.

Travel 31 km west on Highway 591 to the Forestry Trunk Road (Highway 734).

Turn left (south) on the Forestry Trunk Road and travel 13.1 km to a small logging road on the right (1.5 km north of Teepee Pole Creek Bridge).

Turn west (right) on the small logging road and travel 1.2 km.

Look for sign reading "Canadian Forest Service – Espacement Trials – Est. 1967 – Flat Site" on the left. The plots are located directly behind the sign.

Site Description

The Teepee Pole flat site is located in the Upper Foothills ecological subregion of southwest Alberta on a level, well-drained cordilleran till with a fluvioeolian veneer. The soil is a Brunisolic Grey Luvisol, 25 to 56 cm deep (Johnstone 1982b). The ecological moisture regime is mesic, and the nutrient regime is medium. This site was classified in 2003 as having a C1.1 lodgepole pine/green alder plant community.

Results after 36 Years

Tree Growth and Mortality

The mortality for the different spacing treatments at the flat site was relatively low until the most recent measurement period, when there was a sharp increase (up to 5% per year) for most treatments (Fig. 99). As expected, the greatest mortality occurred in the densest stands, and the treatment with 8000 stems per hectare had 70% mortality over the 36-year measurement period. Also as expected, mortality for the treatments with 1000 and 2000 stems per hectare appears to be overtaking mortality for the treatment with 500 stems per hectare.

In general, average diameter increased with decreasing stand density (Fig. 100). However, the diameters of trees in the unthinned plots and in the plots with 4000 and 8000 stems per hectare converged to about 15 cm by the time of the latest measurement. The average diameter in the plots with highest density is 6.5 cm smaller than in the plots with lowest density.

Differences in average heights at the flat site developed slowly over time, so that even at the time of the most recent measurement, average heights among the different treatments were within a 2-m range (Fig. 101). The most recent measurements are beginning to show that lower density plots have shorter average heights than higher density plots.

Stand Development

Stand densities declined more rapidly in plots with higher densities, and the decline was negligible in the two treatments with widest spacing (Fig. 102). It appears that the treatments are converging to a similar density: there was a range of only 1819 stems per hectare at the time of the most recent measurement, much less than the range of 7381 stems per hectare at time of the first measurement. The density in the control plots has decreased faster than in any of the treatments, and at the time of the most recent measurement, density in the control plots was the same as in the densest treatments.

As stand density decreased, average diameter increased, which suggests that the residual trees responded to increased resource availability (Fig. 103). There were no bimodal distributions, which indicates that no appreciable ingrowth occurred in any of the treatments. The height–diameter relationship illustrates that trees within the same diameter class grew taller with increasing stand density, at least up to 2000 stems per hectare (Fig. 104).

Stand basal area increased with density (Fig. 105). As in the other Teepee Pole experimental sites and the related Gregg Burn experiments, even though individual trees grew less in the denser treatments, basal area per unit of stand area was higher because of the greater number of stems remaining. The two highest density treatments (4000 and 8000 stems per hectare) exhibited a loss in basal area over the last measurement interval, as did the control. Nonetheless, the highest density treatment (8000 stems per hectare) had a basal area three times greater than that of the lowest density treatment (500 stems per hectare), even though average individual tree height and diameter were greatest in the latter. The exception to this trend was the control, which in 2003 had a basal area equal to that of the treatment with 4000 stems per hectare.

As for basal area, treatments with higher density had higher total volumes (Fig. 106). It should be noted that both the plots with 8000 stems per hectare and the unthinned plots had a decrease in total volume over the most recent measurement period, likely because of high mortality. Even so, the treatment with 8000 stems per hectare maintained the highest total volume, almost 50 m^3/ha greater than that of the treatment with 4000 stems per hectare.

As for basal area and total volume, stand density contributed more to merchantable volume (for the 13/7 standard) than individual tree growth (Fig. 107). However, the treatments with 2000 and 4000 stems per hectare had similar volumes over the last four measurements, because of the trade-off between tree size and stand density. Merchantable volume for the treatment with 8000 stems per hectare was almost four times that for the treatment with 500 stems per hectare. Unthinned control plots had merchantable volumes similar to those of the treatments with 2000 and 4000 stems per hectare.

With respect to the 15/10 merchantability standard, volume trends were similar to those for total volume, with the exception of the treatment with 2000 stems per hectare, which had a larger 15/10 merchantable volume than the treatment with 8000 stems per hectare until the most recent measurement (Fig. 108). For the larger merchantability standard, the trees in the denser treatments need more time to develop; as this happens, the treatment with 4000 stems per hectare will probably also surpass that with 2000 stems per hectare in terms of merchantable volume.

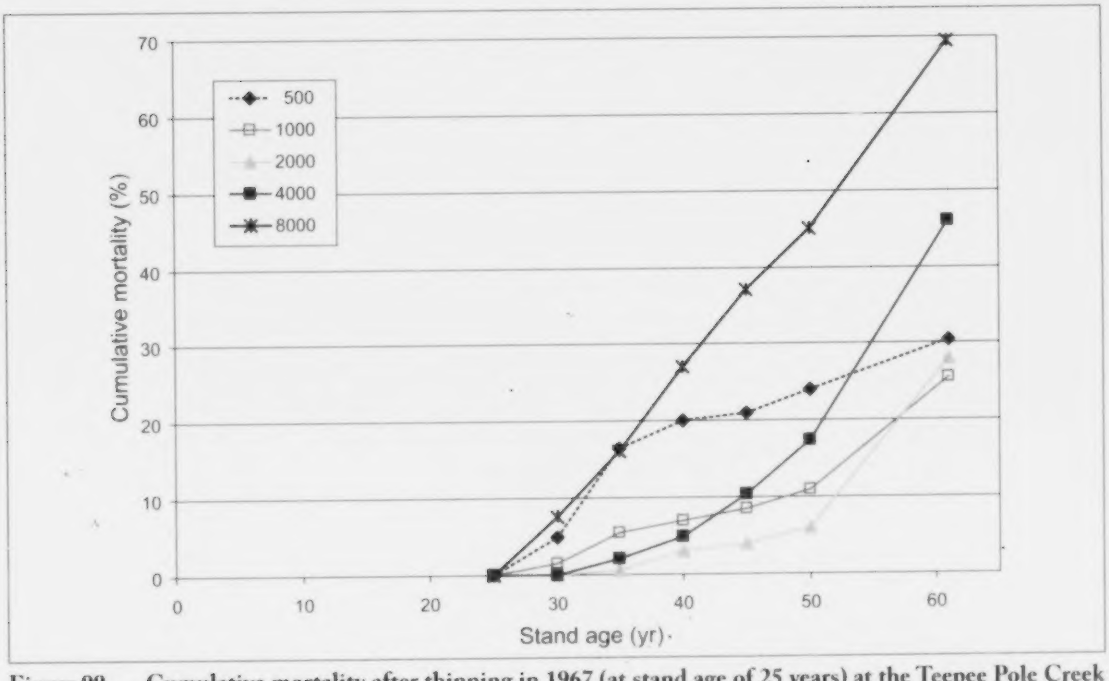

Figure 99. **Cumulative mortality after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek flat site.** Treatments are designated by stand density after thinning (stems per hectare).

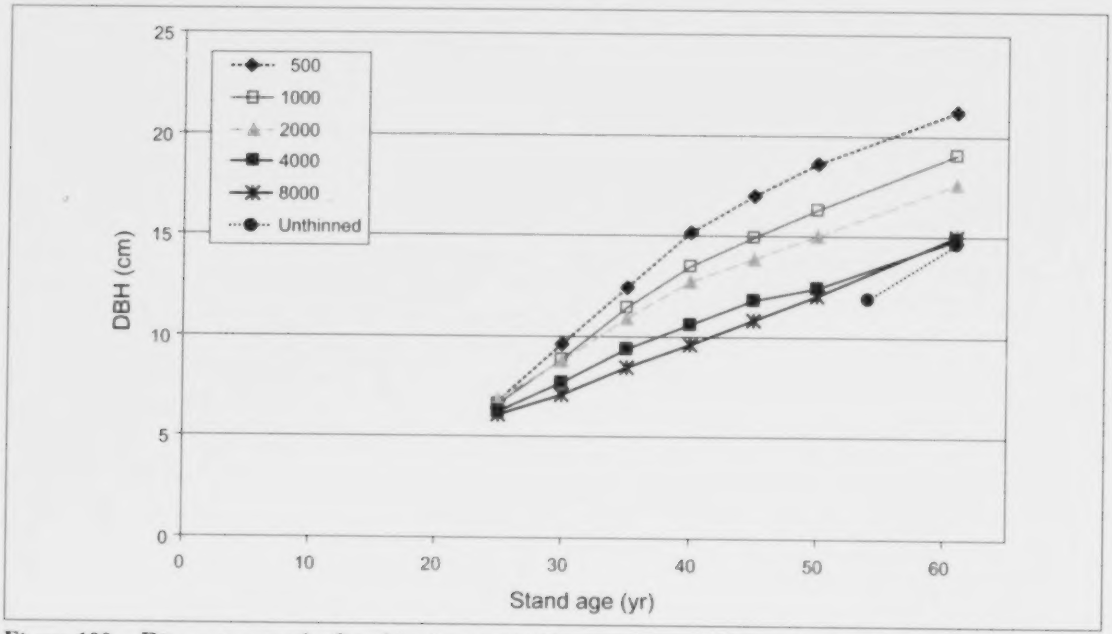

Figure 100. **Diameter growth after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek flat site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

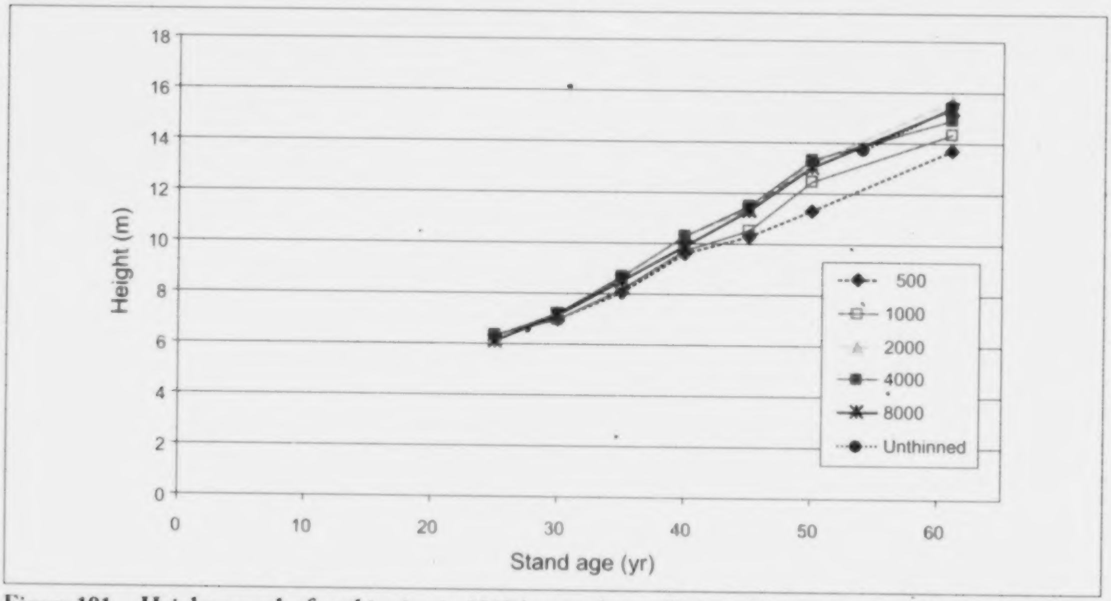

Figure 101. **Height growth after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek flat site.** Treatments are designated by stand density after thinning (stems per hectare).

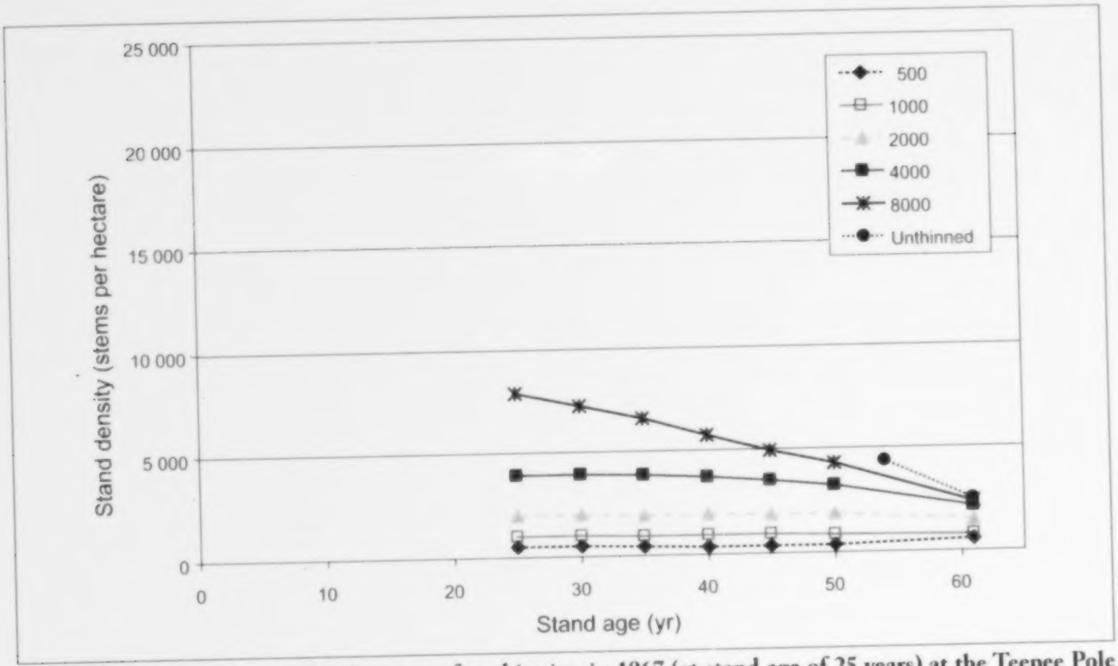

Figure 102. Stand density development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek flat site. Treatments are designated by stand density after thinning (stems per hectare).

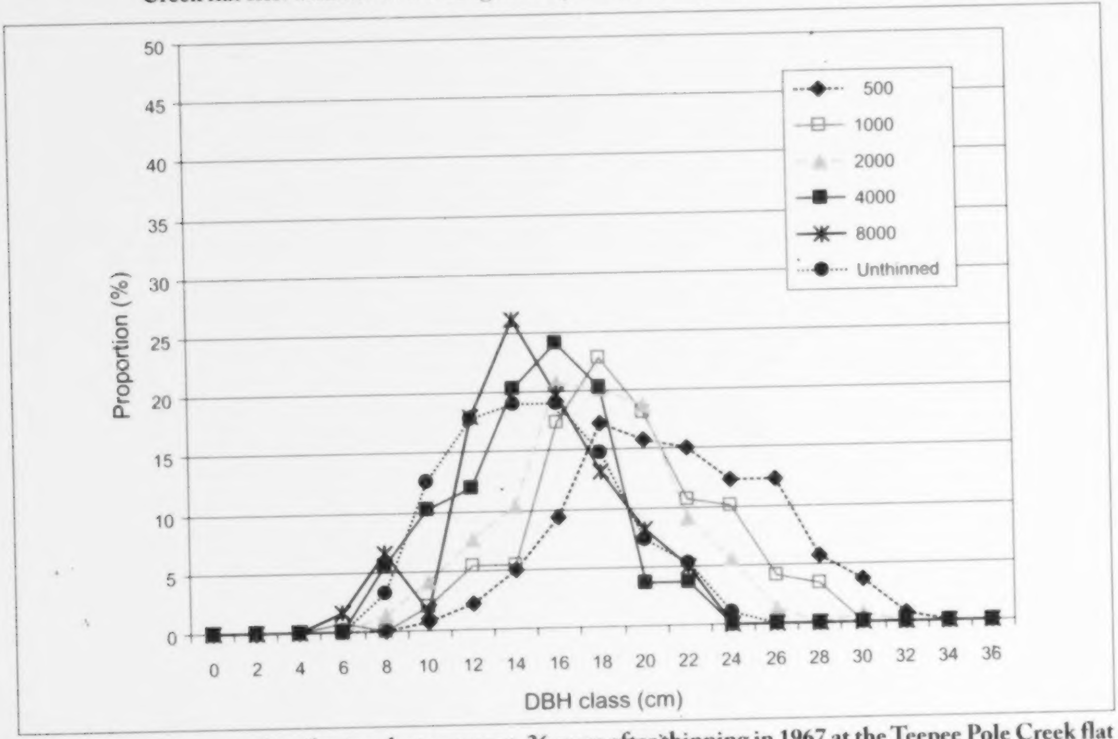

Figure 103. Diameter distribution, by treatment, 36 years after thinning in 1967 at the Teepee Pole Creek flat site. Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

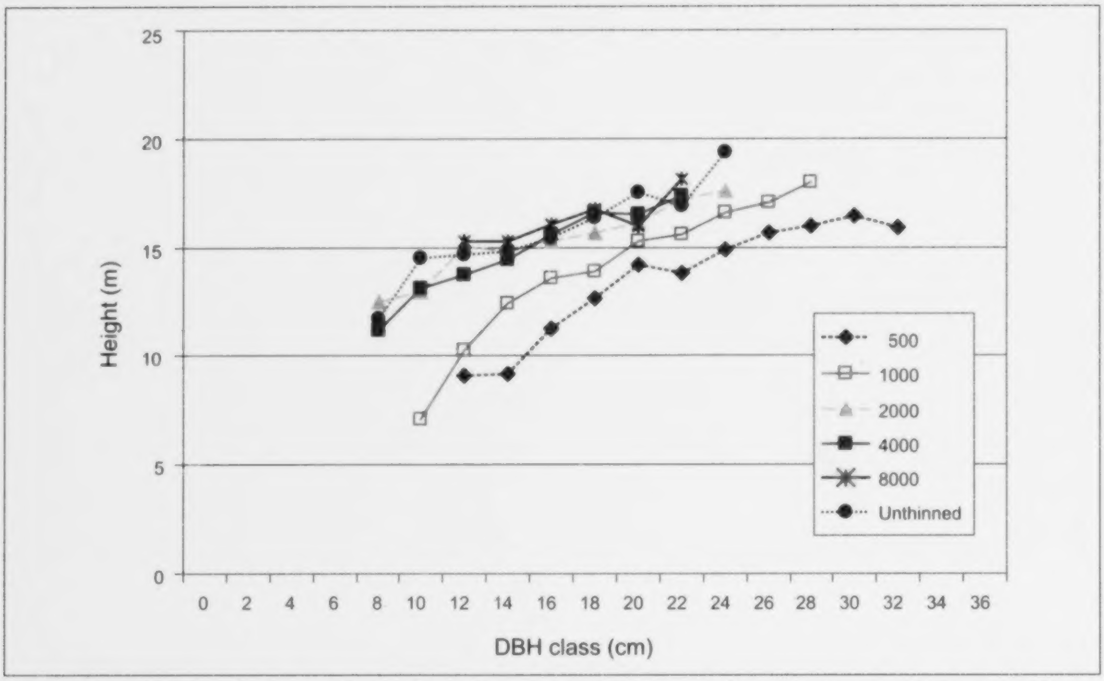

Figure 104. **Height–diameter relationships, by treatment, 36 years after thinning in 1967 at the Teepee Pole Creek flat site.** Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

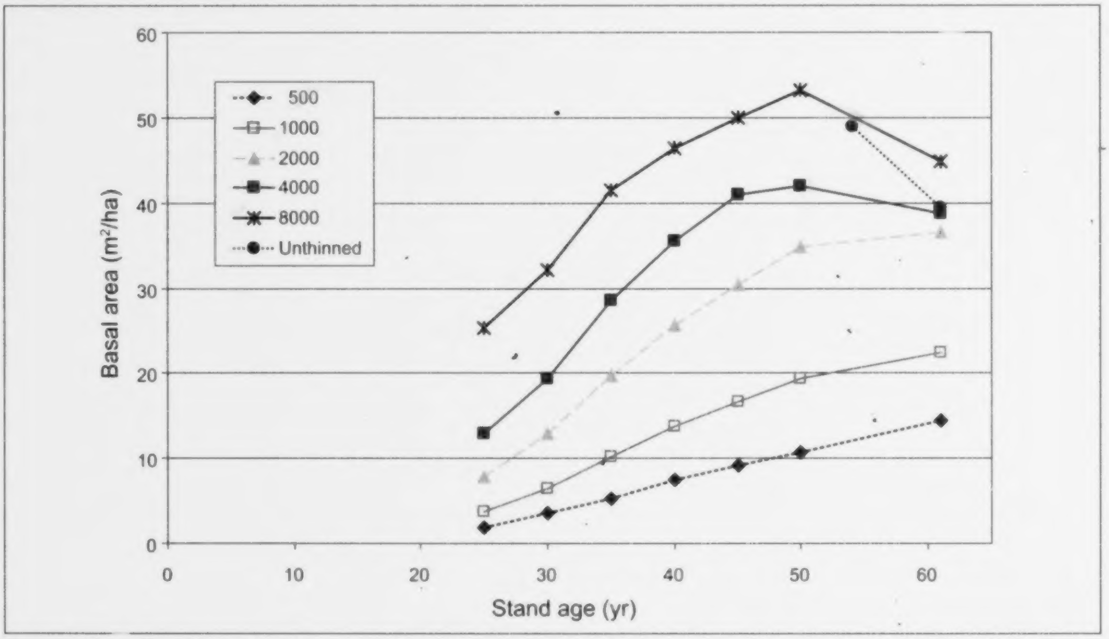

Figure 105. **Basal area development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek flat site.** Treatments are designated by stand density after thinning (stems per hectare).

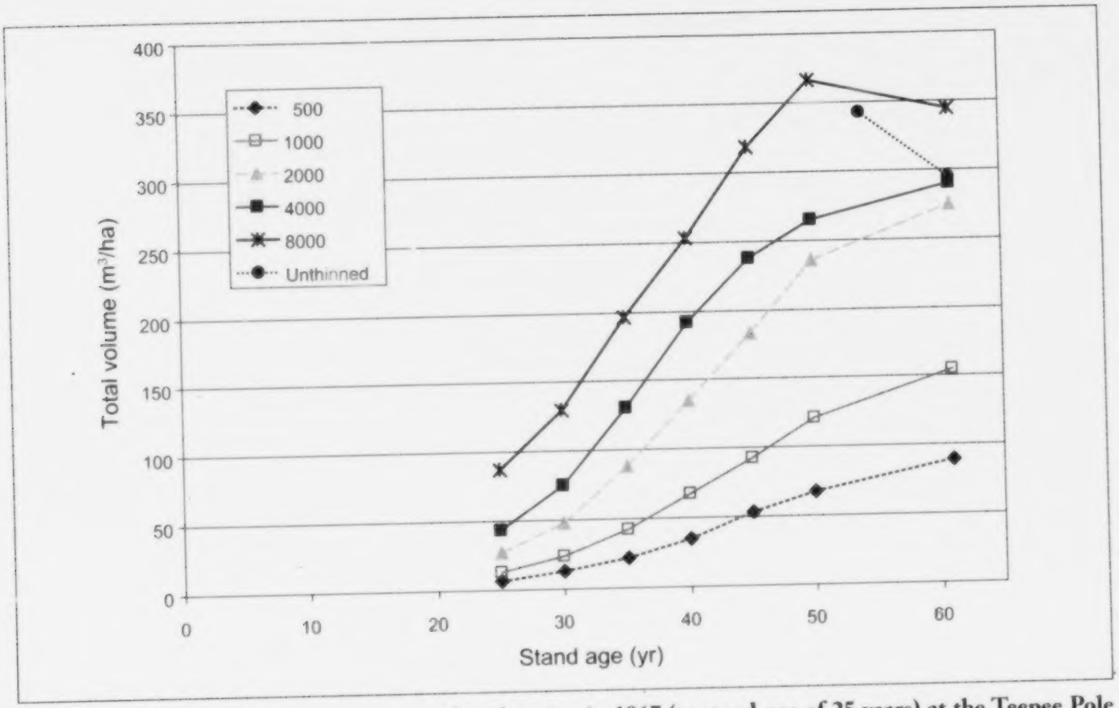

Figure 106. Total volume development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek flat site. Treatments are designated by stand density after thinning (stems per hectare).

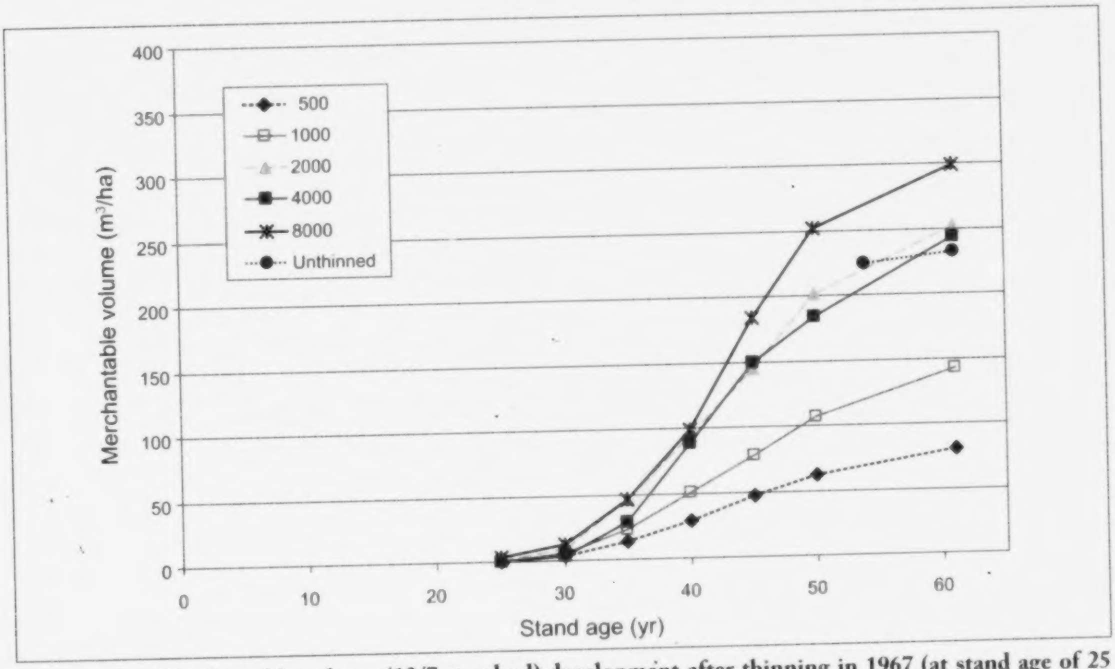

Figure 107. Merchantable volume (13/7 standard) development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek flat site. Treatments are designated by stand density after thinning (stems per hectare).

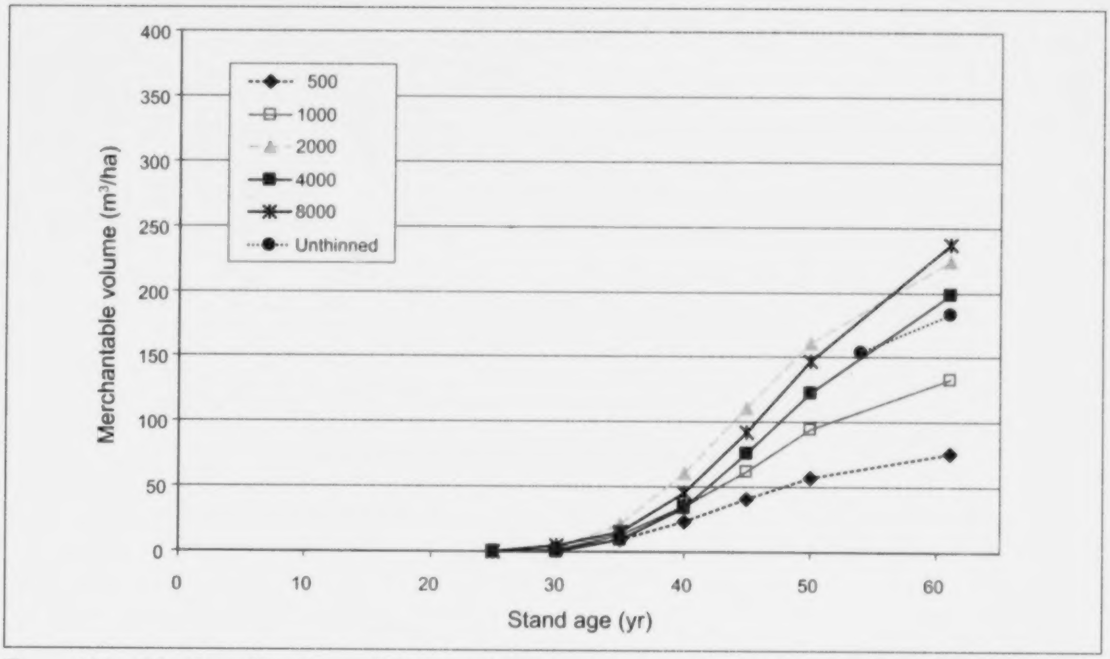

Figure 108. **Merchantable volume (15/10 standard) development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek flat site.** Treatments are designated by stand density after thinning (stems per hectare).

Teepee Pole Creek Spacing Experiment (1967)—North Site

Location and Access

The Teepee Pole Creek north site (51°53.8'N, 115°09.7'W, legal location 13-1-34-9-W5 and 16-2-1-34-9-W5) is located about 55 km southwest of Rocky Mountain House on the north-facing side of the Teepee Pole Creek valley, just off the Forestry Trunk Road. To access the site from Caroline, follow these directions:

Travel 8 km west on Highway 22, to Highway 591.

Travel 31 km west on Highway 591 to the Forestry Trunk Road (Highway 734).

Turn left (south) on the Forestry Trunk Road and travel 15.1 km (0.5 km past the Teepee Pole Creek Bridge).

Look for sign reading "Canadian Forest Service – Espacement Trials – Est. 1967 – North" in a clearing on the east side of the road.

Follow the paint-blazed trail up the hill to the site (about 400 m).

Site Description

The Teepee Pole north site is located in the Upper Foothills ecological subregion of southwestern Alberta on a north-facing slope of well-drained sandy-loam textured, cordilleran till with sandstone bedrock at 65 cm depth. The soil is an Eluviated Eutric Brunisol (Johnstone 1982b). The ecological moisture regime varies from submesic to subhygric, and the ecological nutrient regime from medium-poor to medium-rich. This site was classified in 2003 as having a C1.1 lodgepole pine/green alder plant community for most plots; a B1.1 lodgepole pine/hairy wild rye plant community for the control plots, the treatment plots with 4000 and 8000 stems per hectare in block 1, and the treatment block with 8000 stems per hectare in block 2; and an E1.1 lodgepole pine/green alder/fern plant community for the treatment plot with 500 stems per hectare in block 2.

Results after 36 Years

Tree Growth and Mortality

As expected, greater densities led to higher mortality, the treatment with 8000 stems per hectare showing 60% losses of crop trees by 2003 (Fig. 109). Cumulative mortality was less than 1% per year in the two treatments with widest spacing and up to 2% per year in the treatment with densest spacing.

The average diameter growth in the treatment plots increased consistently with decreasing stand density (Fig. 110). Surprisingly, trees in the control plots had a greater average diameter than those in plots with 8000 stems per hectare, and their average diameter appeared to be increasing at a greater rate during the most recent measurement interval than for any of the spacing treatments. This may be due to the high rates of self-thinning mortality that occurred among the smallest trees in the control plots.

During most of the measurement period, the treatment with 4000 stems per hectare maintained the greatest average height (Fig. 111). However, at the time of the latest measurement, the treatments with 1000 and 2000 stems per hectare had caught up. The control plots and plots with 500 stems per hectare had the same average height in 2003, about 1 m lower than for the three treatments mentioned previously, and the plots with 8000 stems per hectare had an average height that was even lower. The difference in average height among all treatments was only about 1.5 m in 2003.

Stand Development

Stand density followed patterns nearly identical with those at the flat site (Fig. 112). Densities in the different treatments appeared to be converging, and the density of the control plots was slightly lower than that of the treatment with 8000 stems per hectare.

The diameter distributions illustrate a trend toward smaller trees with increasing stand density, as well as an approximately normal distribution of tree size in each spacing treatment (Fig. 113). The control plots had the flattest curve, i.e., a more even distribution of trees over a broader range of diameters than any of the spacing treatments. The height–diameter curves indicate that trees grew taller at a given diameter at higher stand densities, at least up to 4000 stems per hectare (Fig. 114).

Stand basal area increased with stand density (Fig. 115). The highest density treatment (8000 stems per hectare) had a basal area more than three times greater than the basal area for the lowest density treatment (500 stems per hectare) (43 and 13 m^2/ha, respectively). However, basal area growth at high density appeared to be slowing down by the time of the latest measurement. Basal area for the control plots was initially similar to that of the treatment with 8000 stems per hectare but then decreased to a value similar to that for the treatment with 4000 stems per hectare, probably because of high mortality in recent years.

Total volume appears to be largely a function of basal area at this site, in that there were small differences in height across treatments and the patterns of volume development were essentially the same as those observed for basal area (Fig. 116). The total volume for the control plots remained the same for the two most recent measurements, perhaps because high mortality was offset by height growth.

Patterns of merchantable volume at the 13/7 standard differed from those of total volume (Fig. 117). Here, the second highest density (4000 stems per hectare) had the highest merchantable volume (217 m^3/ha). At stand age 35 years, the treatment with 8000 stems per hectare had the lowest 13/7 merchantable volume; however, its merchantable volume increased at a greater rate than for the other treatments, and by stand age 61 years, this density had overtaken all other treatments except that with 4000 stems per hectare. As more of the trees in the 8000 stems per hectare treatment reach the 13/7 standard, this treatment will likely surpass the 4000 stems per hectare treatment in terms of merchantable volume. Over the long run, stand density appears to have a greater influence on merchantable volume than does tree growth.

For the 15/10 standard, the treatment with 2000 stems per hectare had the greatest merchantable volume until the time of the most recent measurement (Fig. 118). By 2003, however, enough trees in the 4000 stems per hectare treatment had reached the standard to allow this treatment to overtake the 2000 stems per hectare treatment in terms of merchantable volume. As this trend continues, the treatment with 8000 stems per hectare is expected to exceed all others in merchantable volume.

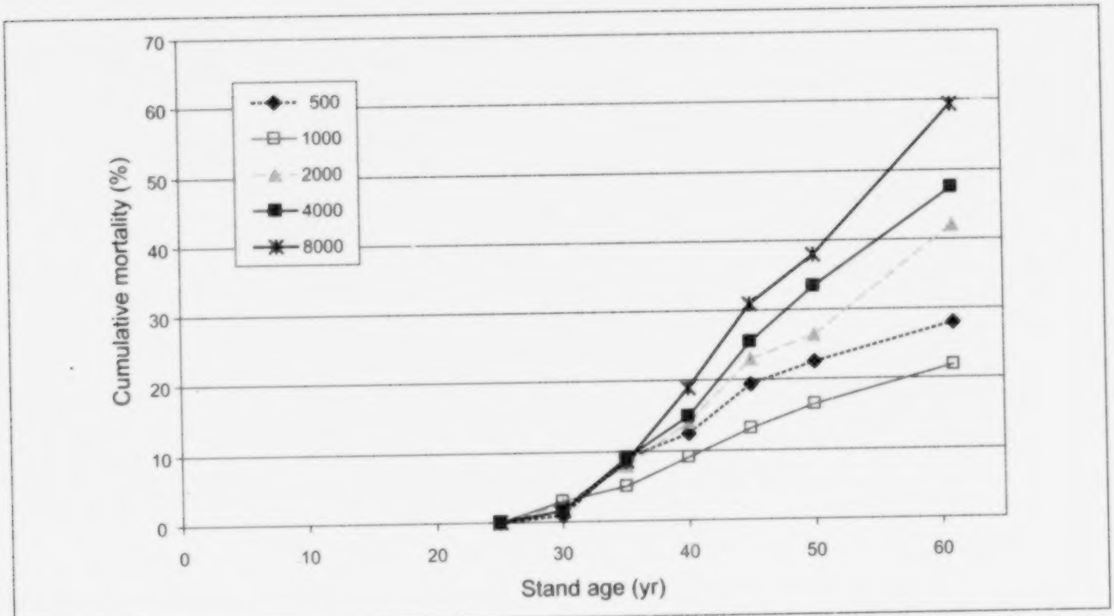

Figure 109. Cumulative mortality after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

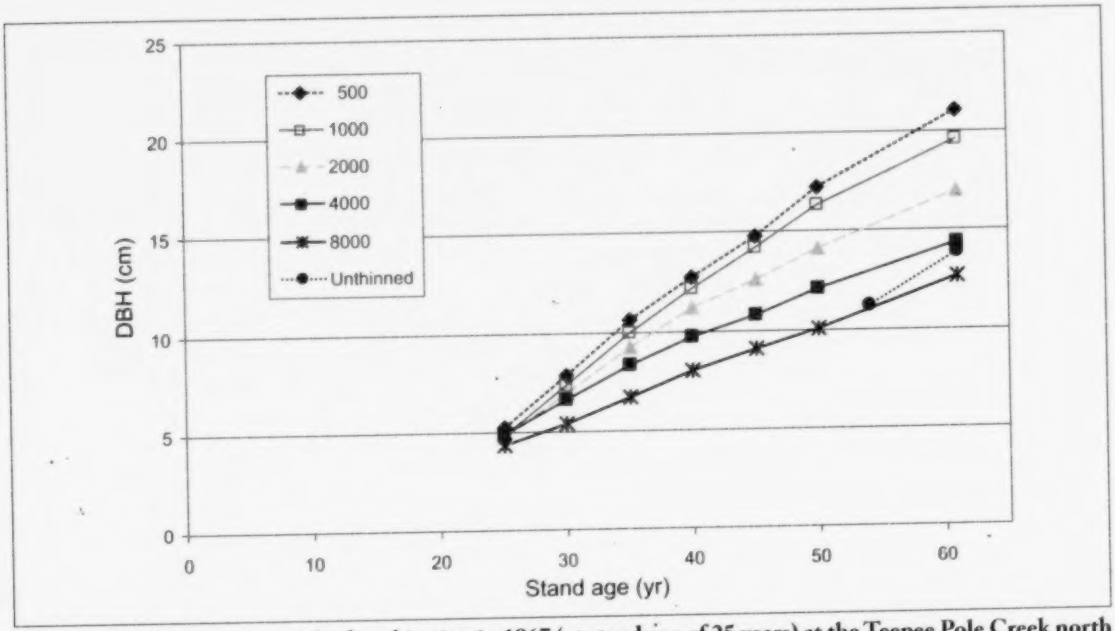

Figure 110. Diameter growth after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

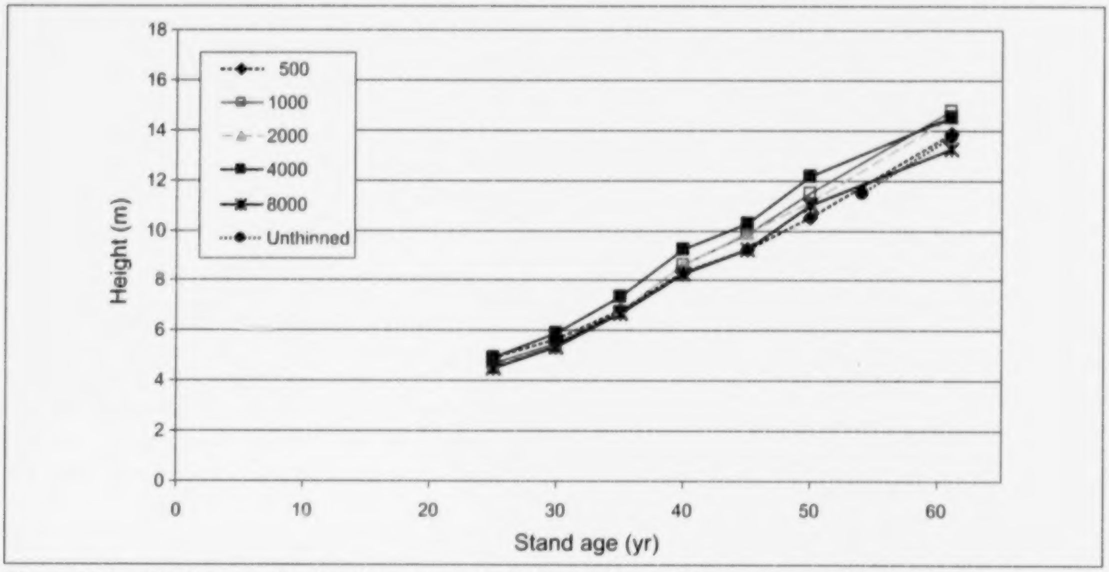

Figure 111. Height growth after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

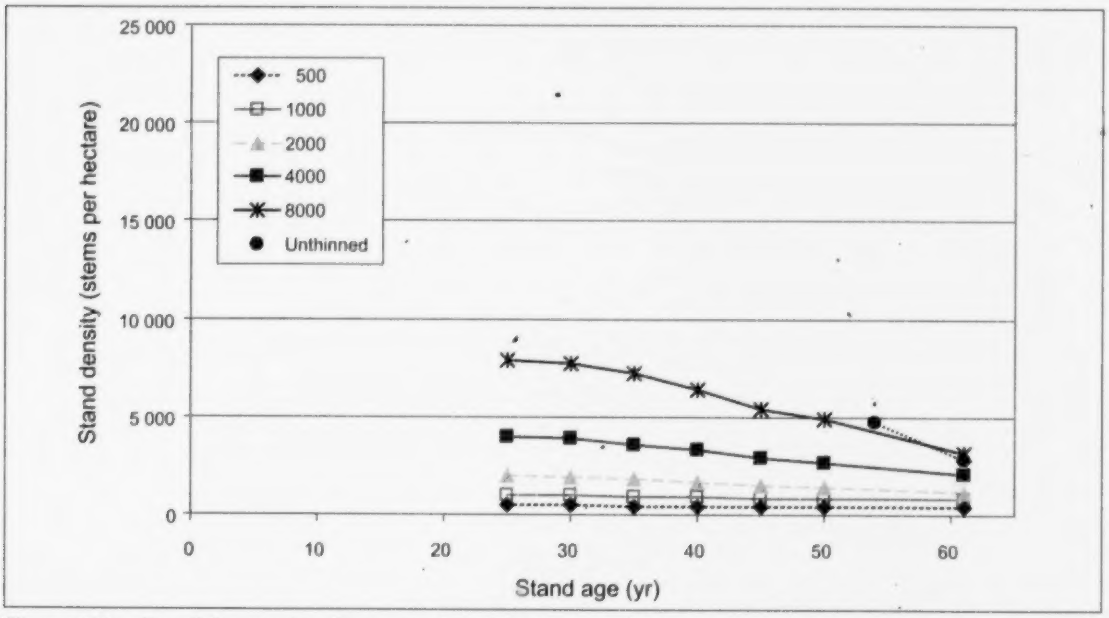

Figure 112. Stand density development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

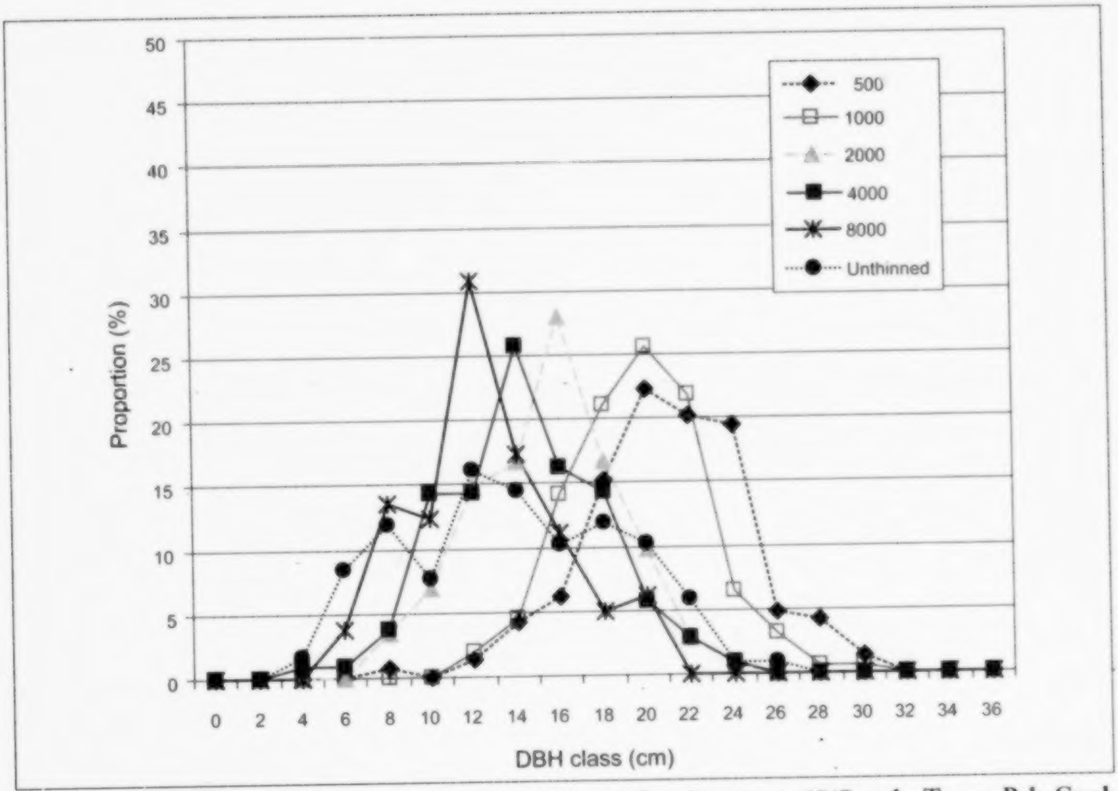

Figure 113. Diameter distribution, by treatment, 36 years after thinning in 1967 at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

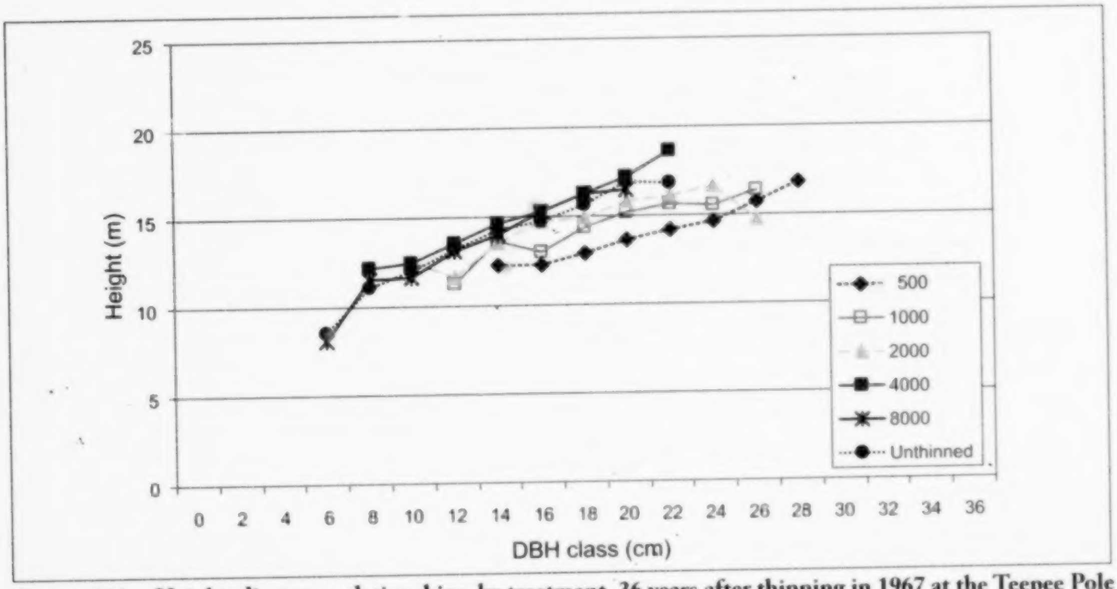

Figure 114. Height–diameter relationships, by treatment, 36 years after thinning in 1967 at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

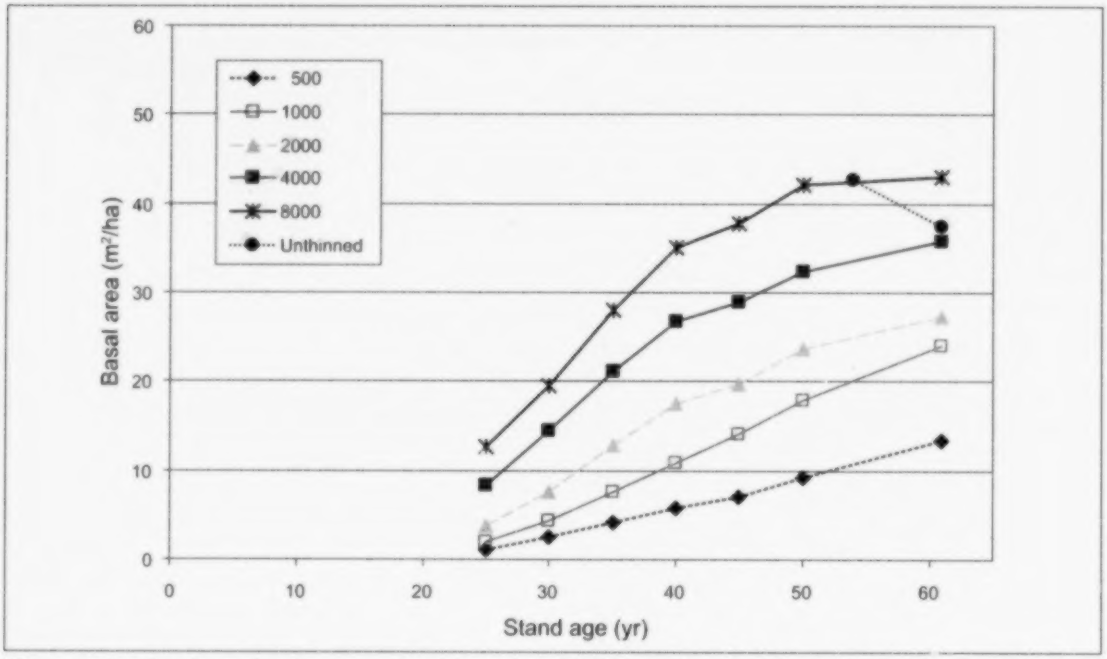

Figure 115. Basal area development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

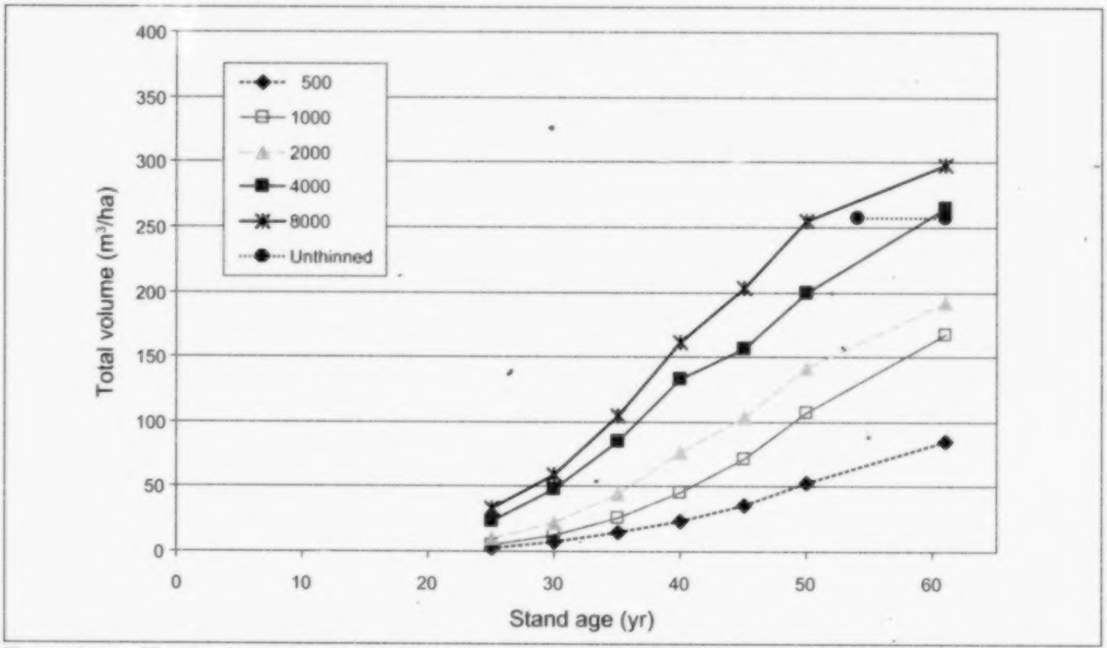

Figure 116. Total volume development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

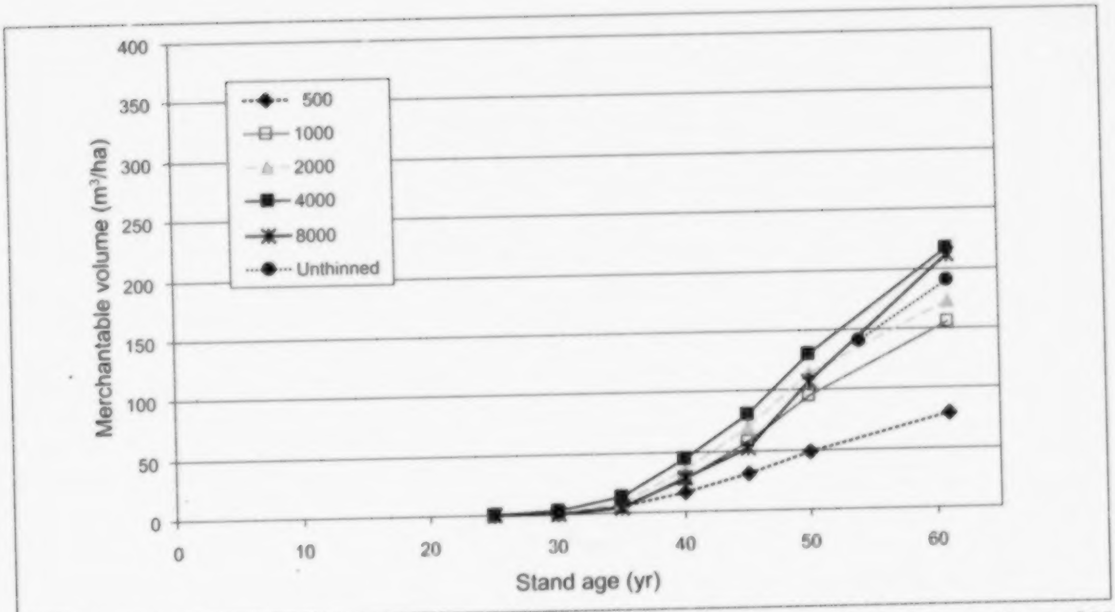

Figure 117. Merchantable volume (13/7 standard) development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

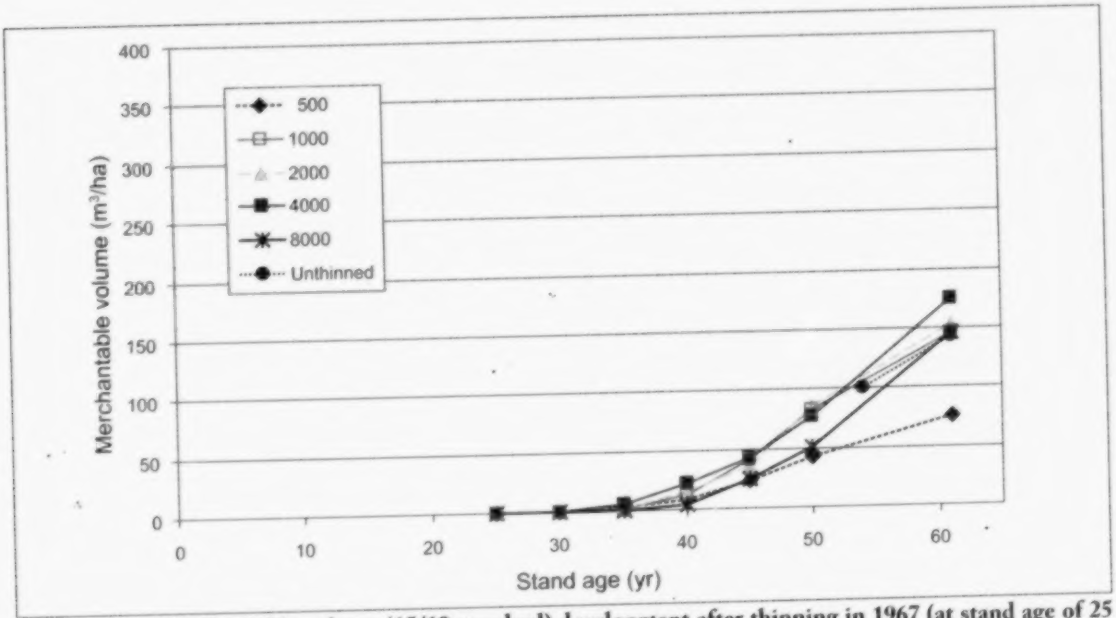

Figure 118. Merchantable volume (15/10 standard) development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site. Treatments are designated by stand density after thinning (stems per hectare).

Teepee Pole Creek Spacing Experiment (1967)–South Site

Location and Access

The Teepee Pole Creek south site (51°53.8'N, 115°11.5'W, legal location 15-3-34-9-W5 and 2-10-34-9-W5) is located about 55 km southwest of Rocky Mountain House on the south-facing side of the Teepee Pole Creek valley, just off the Forestry Trunk Road. To access the site from Caroline, follow these directions:

Travel 8 km west on Highway 22, to Highway 591.

Travel 31 km west on Highway 591 to the Forestry Trunk Road (Highway 734).

Turn left (south) on the Forestry Trunk Road and travel 13.1 km to a small logging road on the right (1.5 km north of Teepee Pole Creek Bridge).

Turn west (right) on the small logging road and travel 2.1 km.

Look for sign reading "Canadian Forest Service – Espacement Trials – Est. 1967 – South" on the right.

Follow trail (marked with paint-blazed trees) about 100 m up the hill.

Site Description

The Teepee Pole south site is located in the Upper Foothills ecological subregion of southwestern Alberta on a south-facing slope of well-drained cordilleran till with sandstone bedrock at 60 cm depth, but becoming more shallow and drier toward the western edge of the site. The soil is a Brunisolic Grey Luvisol (Johnstone 1982b). Most of the site has a submesic moisture regime and a medium ecological nutrient regime, and was classified in 2003 as having a C1.1 lodgepole pine/green alder plant community. The western edge of the site exhibits truncated development because of the shallow depth to bedrock (Johnstone 1982b). This part of the site has a subxeric moisture regime and poor nutrient regime and was classified as having a B1.2 lodgepole pine/green alder/hairy wild rye plant community. Both replicates of the treatments with 2000 and 8000 stems per hectare are located on these shallow soils.

Results after 36 Years

Tree Growth and Mortality

The mortality of crop trees on the south-facing site has not been consistent over time or among the treatments (Fig. 119). Mortality rates have been moderate to high; the treatment with 500 stems per hectare had the highest mortality shortly after thinning, and the other treatments experienced the highest mortality over the latest measurement interval. Cumulative mortality was highest for the treatment with 4000 stems per hectare (60%) and lowest for the treatment with 2000 stems per hectare (28%).

Diameter development was roughly related to stand density; the two lowest density treatments shared the highest diameter growth curve, while the treatment with the highest density had the shallowest diameter growth curve (Fig. 120). However, at the time of the latest measurement, the diameter for trees in control plots was closest to the value for plots with 4000 stems per hectare, and the average diameter for the plots with 2000 stems per hectare was less than both of those. Given that diameter development curves at the other two sites in this experiment were clearly and consistently ordered by stand density, it appears that the lower site quality for the western plots (2000 and 8000 stems per hectare) inhibited their diameter growth.

Average height development did not show any relationship with stand density (Fig. 121). In 2003, trees in the unthinned plots and the plots with 1000 stems per hectare had the tallest average height, followed by the plots with 4000 and 500 stems per hectare and then the plots with 2000 and 8000 stems per hectare, which were on lower quality soil. This south-facing site differs from the others in the Teepee Pole Creek experiment because there were considerable differences in average height among the treatments (a range of nearly 6 m by 2003), as well as a lack of a relationship between height and density. It may be that there is more site variability here than at the other two locations, and this variability may be exacerbated by the southerly aspect, which reduces sunlight and energy constraints on growth and increases the importance of edaphic factors.

Stand Development

As for the other two sites in this experiment, only the treatments with the closest spacing experienced significant declines in density (Fig. 122). There has been almost no change in density in the treatments with 2000 or fewer stems per hectare. The high mortality in the control plots (as noted above) has driven stand density below that of the treatment with 4000 stems per hectare.

The diameter distributions provide further evidence that the treatments with 2000 and 8000 stems per hectare are on lower quality soil, as they had proportionally more trees with smaller diameter, even relative to the unthinned control plots (Fig. 123). Those two treatments aside, there was a general trend of lower density treatments having more larger diameter trees; the treatments with 500 and 1000 stems per hectare had very similar curves, as did the treatment with 4000 stems per hectare and the control. For the treatments with 2000 and 8000 stems per hectare, the height–diameter relationships appear to have been less influenced by differences in site quality than was diameter growth; however, trees growing at lower densities were not as tall at a given diameter as those growing at higher densities (Fig. 124).

The slow diameter growth in the plots with 2000 and 8000 stems per hectare (on the poorer quality site) is reflected in the stand basal area, although within each site type a trend of increasing basal area with increasing stand density was observed (Fig. 125). High mortality combined with smaller trees reduced basal area in the unthinned control plots to a level lower than that for the treatment with 4000 stems per hectare. Total volume showed the same trends as for basal area development, although the treatment with 4000 stems per hectare had significantly more volume than the treatment with 8000 stems per hectare, and the treatments with 2000 and 1000 stems per hectare were not significantly different from each other (Fig. 126). The decline in both basal area and total volume in plots with 4000 stems per hectare can be attributed to the recent high mortality rates.

The data for 13/7 merchantable volume followed expected trends, the treatments with greater density having higher merchantable volumes, after site quality differences were taken into account (Fig. 127). The smaller trees on the poor sites (2000 and 8000 stems per hectare) had a significant negative effect on merchantable volumes for these treatments, particularly at the higher density, which had merchantable volumes below those of the treatment with 500 stems per hectare for much of the measurement period. Although the unthinned plots had higher merchantable volume at stand age of 54 years, high mortality led to a sharp decline in 13/7 merchantable volume (to 197 m^3/ha), well below the value for the treatment with 4000 stems per hectare (250 m^3/ha).

Like the 13/7 merchantable volumes, the 15/10 merchantable volumes were higher for denser stands, but these data also illustrated the poor site quality of the treatments with 2000 and 8000 stems per hectare (Fig. 128). The most noticeable difference between the 13/7 and 15/10 standards was that the highest density treatment did not surpass the lowest density treatment until the last measurement period, and it still has not reached the level of the treatment with 2000 stems per hectare. As more trees reach the merchantable standard, the densest treatment is expected to surpass more of the other treatments in terms of merchantable volume.

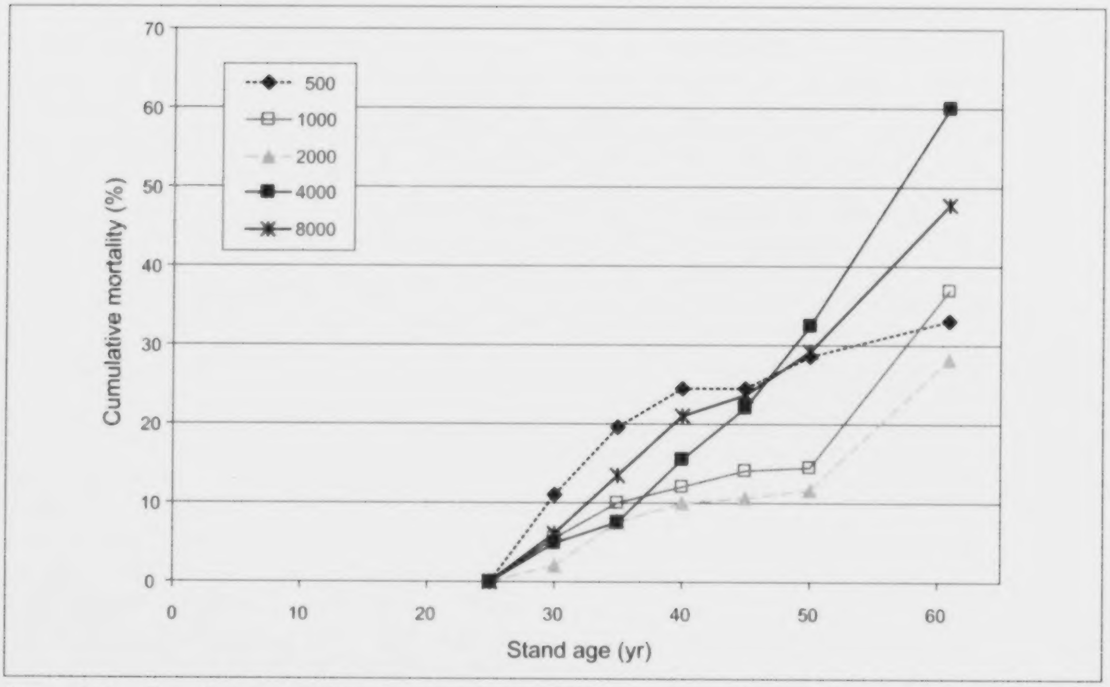

Figure 119. Cumulative mortality after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek south site. Treatments are designated by stand density after thinning (stems per hectare).

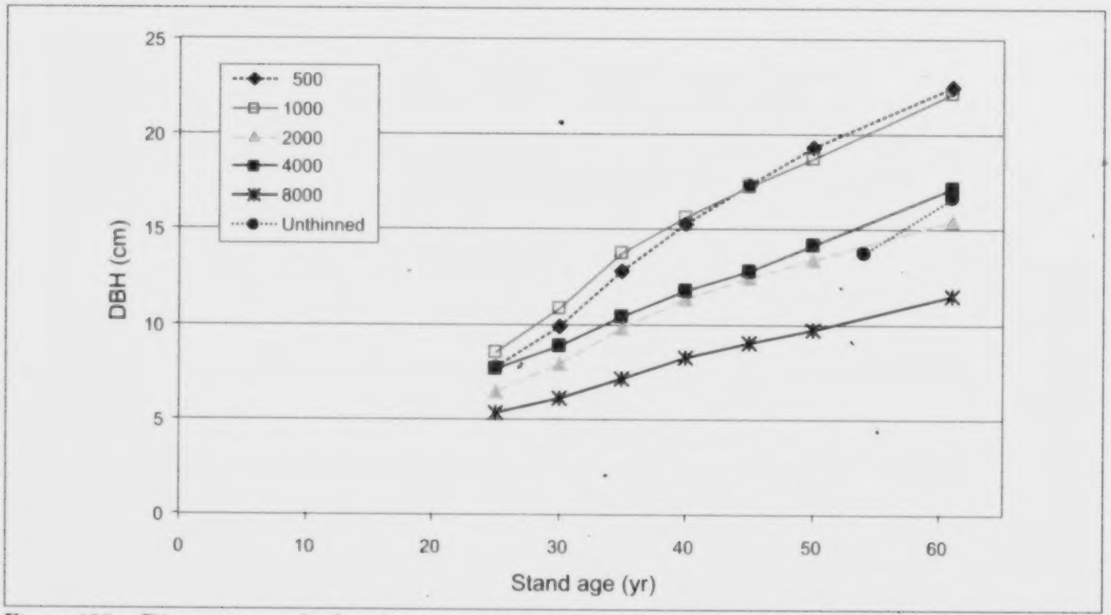

Figure 120. Diameter growth after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek south site. Treatments are designated by stand density after thinning (stems per hectare). DBH = diameter at breast height.

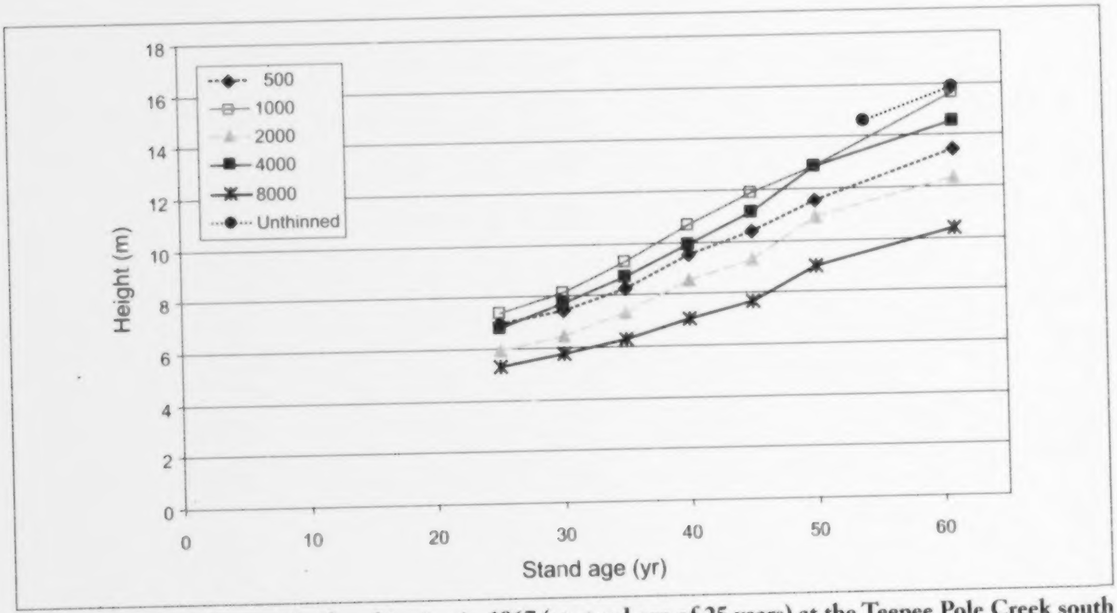

Figure 121. Height growth after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek south site. Treatments are designated by stand density after thinning (stems per hectare).

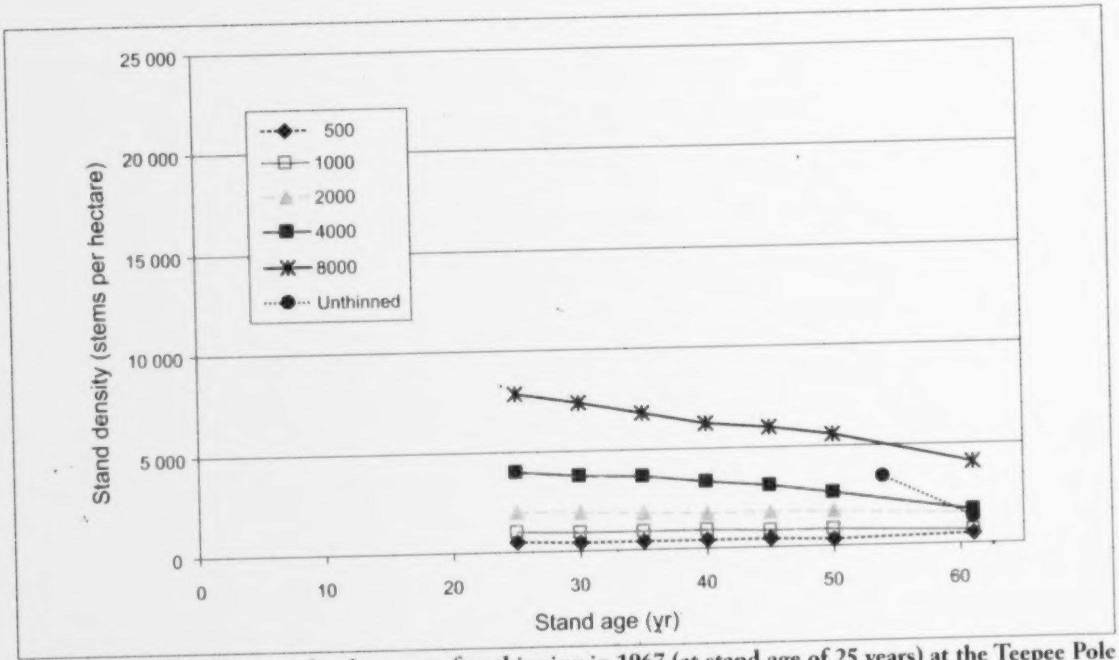

Figure 122. Stand density development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek south site. Treatments are designated by stand density after thinning (stems per hectare).

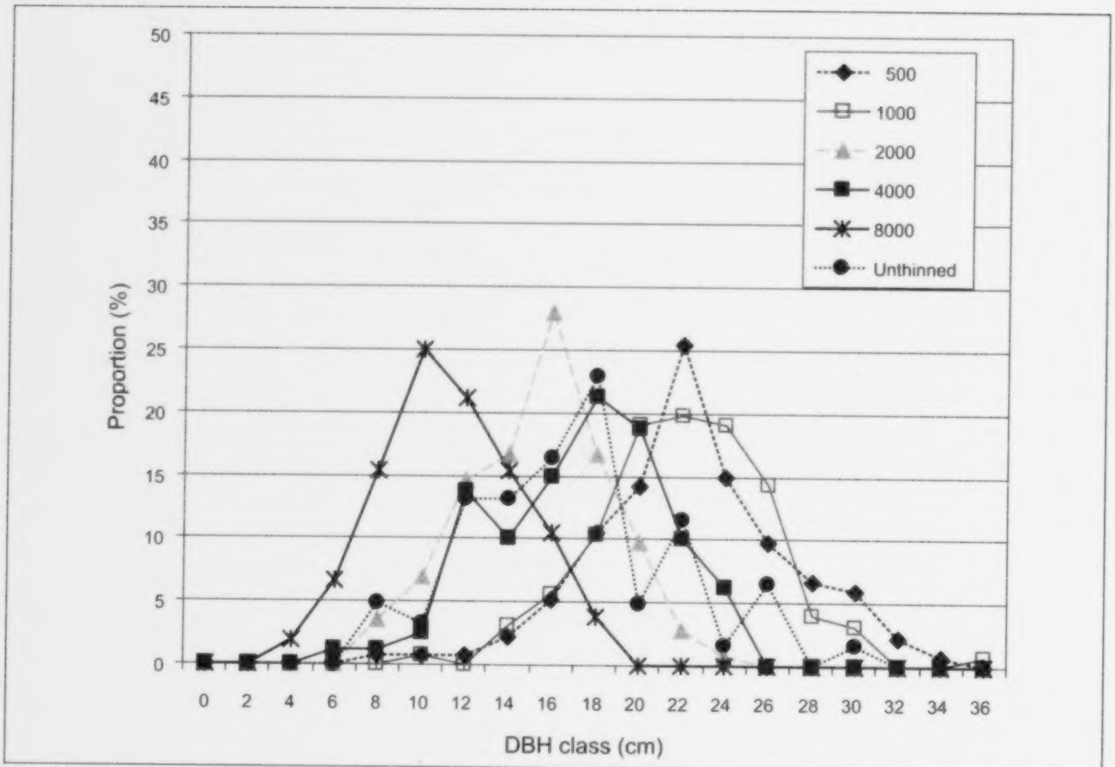

Figure 123. Diameter distribution, by treatment, 36 years after thinning in 1967 at the Teepee Pole Creek south site. Treatments are designated by stand density after thinning (stems per hectare).

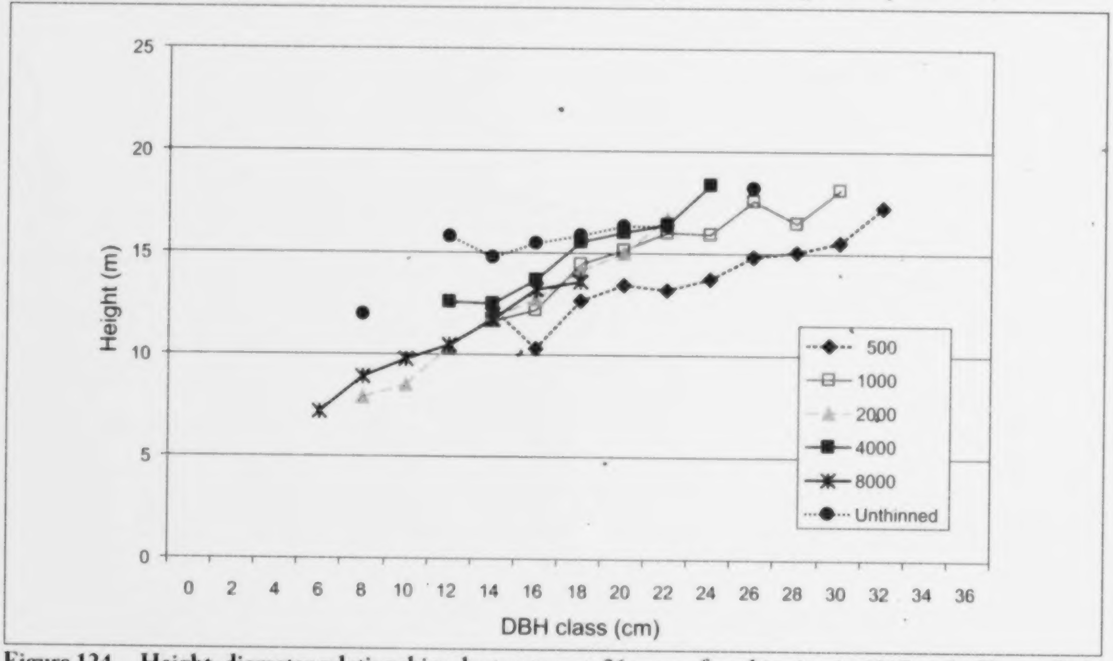

Figure 124. Height–diameter relationships, by treatment, 36 years after thinning in 1967 at the Teepee Pole Creek south site. Treatments are designated by stand density after thinning (stems per hectare).

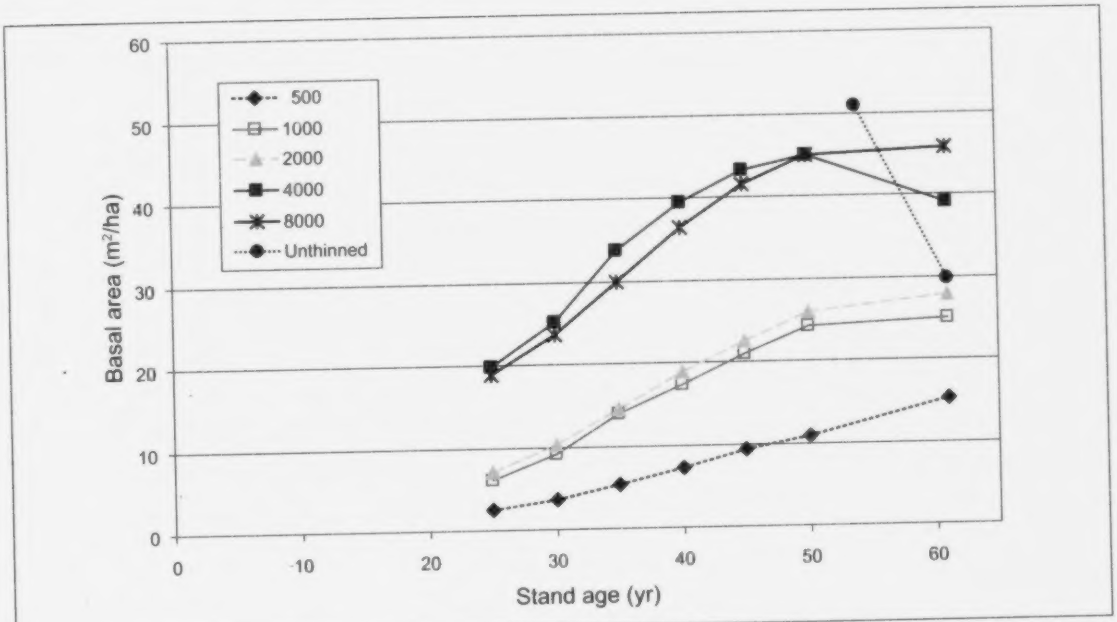

Figure 125. Basal area development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek south site. Treatments are designated by stand density after thinning (stems per hectare).

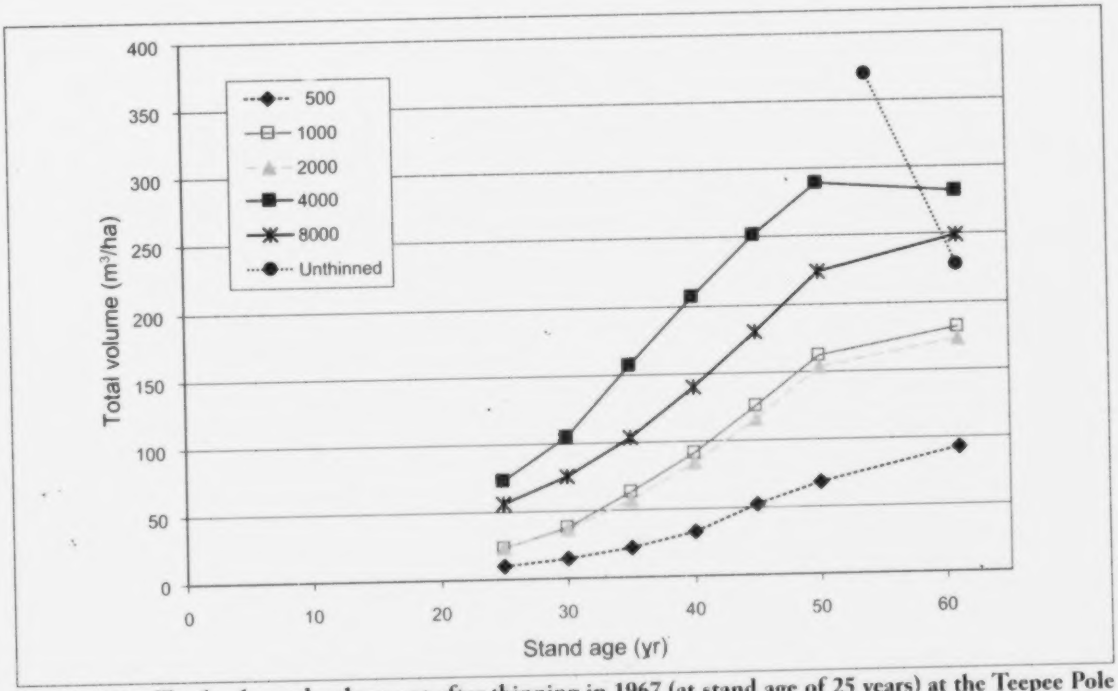

Figure 126. Total volume development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek south site. Treatments are designated by stand density after thinning (stems per hectare).

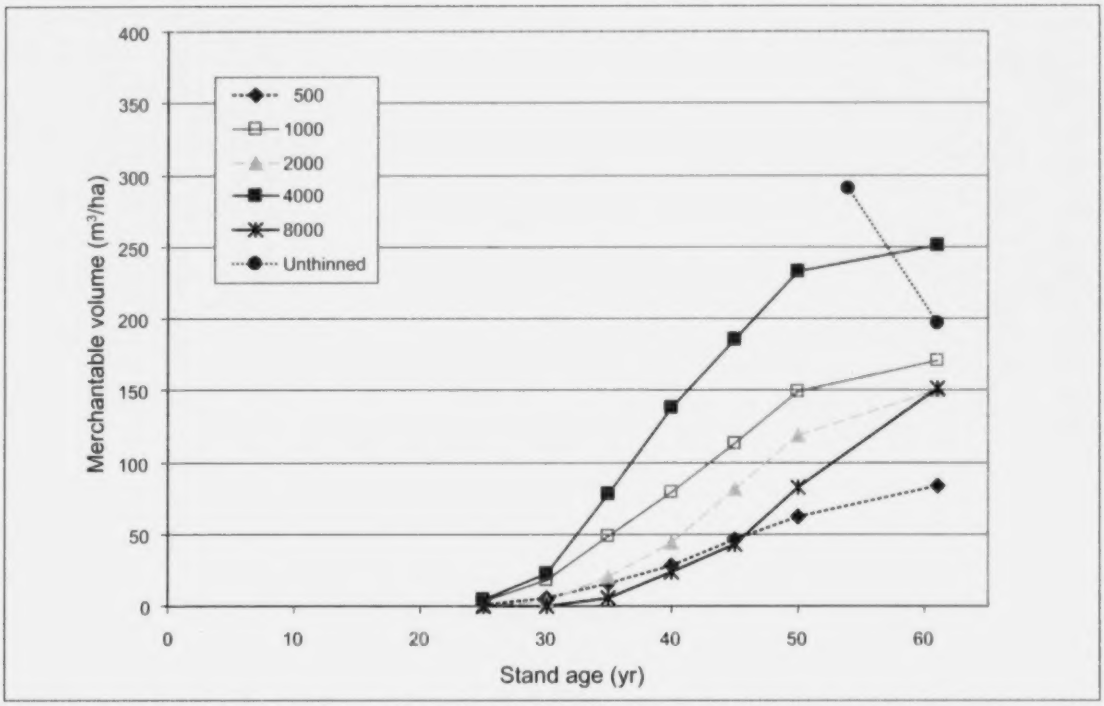

Figure 127. **Merchantable volume (13/7 standard) development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site.** Treatments are designated by stand density after thinning (stems per hectare).

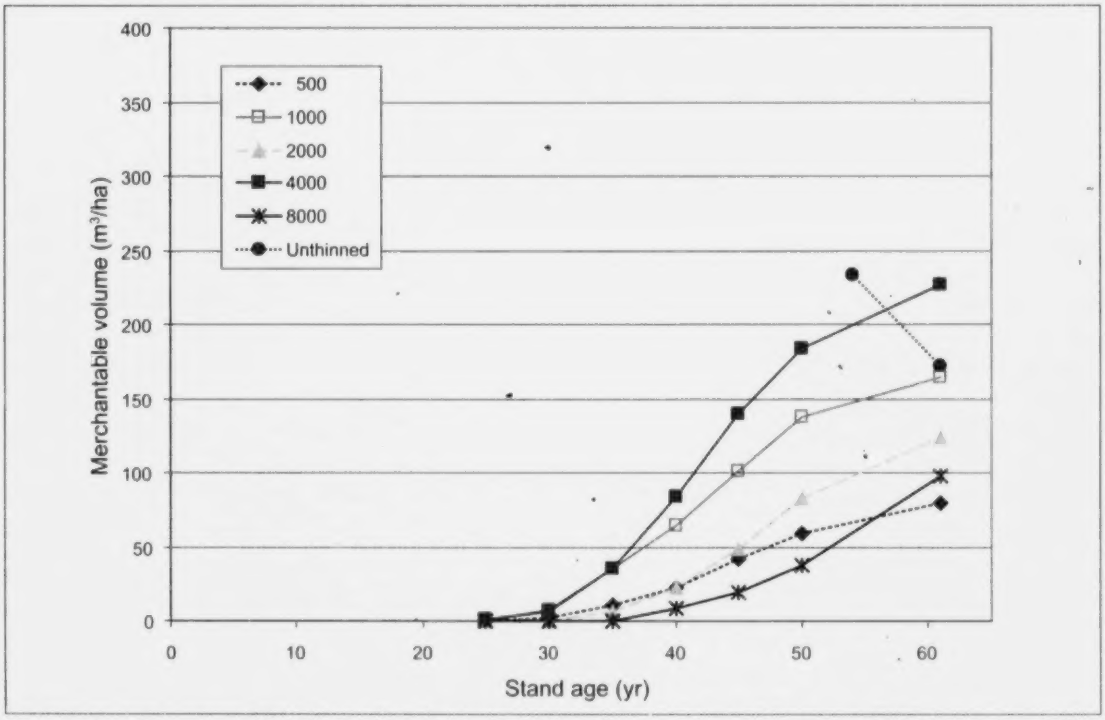

Figure 128. **Merchantable volume (15/10 standard) development after thinning in 1967 (at stand age of 25 years) at the Teepee Pole Creek north site.** Treatments are designated by stand density after thinning (stems per hectare).

Clearwater Fertilization and Thinning Experiment (1968)

Location and Access

The Clearwater experiment site (51°60'N, 115°14'W, legal location N½-9-35-9-W5) is located in the Clearwater Valley, 47 km southwest of Rocky Mountain House, Alberta. To access the site from Caroline, follow these directions:

Travel 8 km west on Highway 22 to Highway 591.

Travel 29 km west on Highway 591 to the access road for the experiment site.

Look for corner signs and blue boundary paint surrounding the treatment plots on the north side of the road.

One control plot is located 400 m along the trail on the south side of the highway, and the other two control plots are north and south of the road, 250 m farther west along the highway.

Establishment and Objectives

The Clearwater fertilization experiment was established in 1968 by J. Soos and I.E. Bella of the federal Department of Forestry and Rural Development, Forestry Branch, in a 72-year-old lodgepole pine stand that had been commercially thinned for production of fence posts. The objective of the experiment was to examine the effect of different rates and compositions of fertilization applied shortly after thinning on the growth of crop trees and the ingrowth of smaller trees to merchantable size classes. The idea was to redistribute growth on fewer selected trees and to eliminate mortality. Fertilization after thinning ensured that only future crop trees would benefit from the added nutrients. It was hoped that the combined treatment effect would significantly improve merchantable yield.

The fertilization treatments were applied in the fall as a randomized incomplete factorial design. A fertilization control was included in the experimental design, but no thinning control was established. Plots in neighbouring unthinned stands from a different project were used as pseudocontrols for thinning. One previous publication reported 7-year results for this experiment (Bella 1978).

Site Description

The Clearwater experiment site is in the Lower Foothills ecological subregion of southwestern Alberta, situated on the valley floor, with Podzolic Grey Luvisol soils developed on level to undulating coarse outwash material with an alluvial veneer (Peters and Bowser 1960). Ecological site classification in 2005 assigned this site to the D1.3 lodgepole pine/Canada buffalo-berry plant community, with a mesic moisture regime, poor to medium nutrient regime, and good drainage. Soil sampling in 1975 showed 3.4 µg/g of exchangeable nitrogen (N), 19.4 µg/g of phosphorus (P), and 134 µg/g of potassium (K) in the upper 30 cm (Bella 1978).

Experimental Design and Treatments

The Clearwater experiment was established in 1968 in a 72-year-old medium productivity stand of essentially pure lodgepole pine. Before thinning, the stand supported 2500 trees per hectare, with a basal area of 33.4 m^2/ha and an average diameter of 13 cm. The site index (base age 70 years) was 17.4 m (Kirby 1975). The thinning was of intermediate intensity and removed smaller trees in order to release the larger, more vigorous ones. Stand density was reduced by 66% and basal area by 55%, and average diameter increased by 16% after thinning.

Fertilization plots were 0.04-ha square plots with 4-m minimum buffers between them. Fourteen treatments were replicated 3 times for a total of 42 plots (Table 3). N, P, and S were broadcast by hand in the form of urea, concentrated superphosphate, ammonium phosphate, and ammonium phosphate sulfate.

Table 3. Fertilization treatments used in the Clearwater experiment[a]

		N112			N673	
	N0, S0	S0	S28	S84	S0	S28
P0	X	X			X	
P56	x	x	x		x	x
P168	x	x	X	x	x	X

[a] N = nitrogen, P = phosphorus, S = sulphur; numeric values indicate kilograms per hectare applied. X = treatment applied and under active study, x = treatment applied but not currently under study.

All living trees in each fertilization plot were tagged, and diameter at breast height was measured. In 1968 and 1975, heights were measured for a subsample of trees representing a range of sizes; in 2005, the height of all trees was measured. Plots used as pseudocontrols for thinning were established in 1951 as part of project A-17, "Growth and Yield of Natural Lodgepole Pine Stands." Plots were of different sizes and shapes; two of the pseudocontrols were the same age as the experimental stand, and the third was 21 years older.

Results after 37 Years

These results are based on data from 1975 and 2005 measurements. Data from 1968 are not available at this time, and values shown for that year are taken from Bella (1978).

Tree Growth and Mortality

Crop trees (those remaining after thinning and tagged in 1968) showed a range of 19 percentage points in mortality over the measurement period (Fig. 129). The addition of P and S was associated with increased mortality, by 11 percentage points in the N112PS treatment relative to N112 and by 19 percentage points in the N673PS treatment relative to N673. Mortality in the unfertilized control plots was within 3 percentage points of mortality in the N112 and N673 treatments.

Over the 30-year period between 1975 and 2005 only trees in the N673PS treatment plots had faster diameter growth than those without fertilization (Fig. 130). Trees in the N673PS treatment plots grew 7.1 cm to an average diameter of 23.0 cm in 2005, whereas those in the unfertilized treatment plots grew 6.2 cm to an average diameter of 21.4 cm. Trees in the N112PS and the N673 treatment plots had similar diameter gains (5.8 and 5.6 cm, respectively). The addition of P and S seemed to have a positive effect on diameter growth, as the slowest growth was seen with the N112 treatment. This treatment was associated with an increase of only 4.5 cm, to 20.6 cm, the lowest average diameter of all treatments.

Fertilization was apparently not a limiting factor in height growth, as trees in the unfertilized treatment plots grew 2.0 m in height over the 30-year measurement period, more than trees in any other treatment (Fig. 131). In 2005, average height was 17.6 m for trees in the unfertilized treatment plots and 20.5 m for trees in the unthinned, unfertilized plots. Trees in the N673PS treatment plots reached the greatest average height (18.5 m) but grew only 0.2 m more over the measurement period than either the N673 or the N112PS trees; trees in the N112 treatment plots grew only 0.7 m and reached an average height of only 17.4 m.

Stand Development

All treatments showed a sharp decline in stand density from 1968 through 1975 (Fig. 132). Ingrowth of smaller trees increased stand density in the unfertilized and low N treatment plots in the 1975–2005 interval, despite the mortality of crop trees. There was very little ingrowth in the plots with high N treatments, and stand densities declined through 2005. The addition of P and S seemed to be associated with slightly reduced stem densities.

The lack of ingrowth that kept stand densities low in the high N treatment plots was also evident in the diameter distributions: the high N treatments had very low proportions of smaller diameter trees and the greatest proportions of larger diameter trees (Fig. 133). Fertilization had little effect on stem slenderness, as all treatments followed the same height–diameter curve; however, for a given diameter, tree height in the thinned treatments was significantly less than in the unthinned control (Fig. 134).

In 1975, total basal area was highest for trees in the N673 treatment plots (18.5 m^2/ha), and the other treatment plots had about 16 m^2/ha basal area (Fig. 135). However, over the next 30 years the rate of increase in basal area was highest for the unfertilized trees (0.48 $m^2\ ha^{-1}\ yr^{-1}$). Basal area increment increased with increasing N and decreased with the application of P and S (0.28, 0.12, 0.40, and 0.30 $m^2\ ha^{-1}\ yr^{-1}$ for N112, N112PS, N673, and N673PS treatments, respectively).

Total and merchantable volumes followed the same pattern as basal area (Fig. 136, 137, and 138). The low nitrogen treatments were associated with the lowest rates of merchantable volume increment, and the high nitrogen treatments were associated with the highest rate, but the addition of P and S had a large negative effect on volume increment, especially with high N fertilization. Volume increments for trees in the unfertilized and N673PS treatments were similar, and these increments were greater than those observed with the other treatments. Volumes in the unthinned plots were much greater than those in the treatment plots.

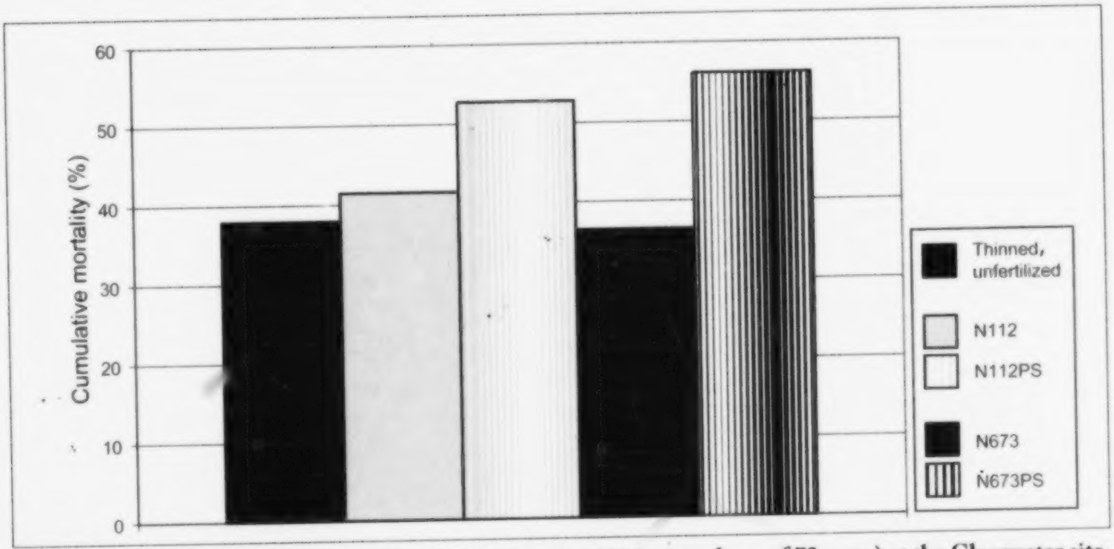

Figure 129. **Cumulative mortality after fertilization in 1968 (at stand age of 72 years) at the Clearwater site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]).

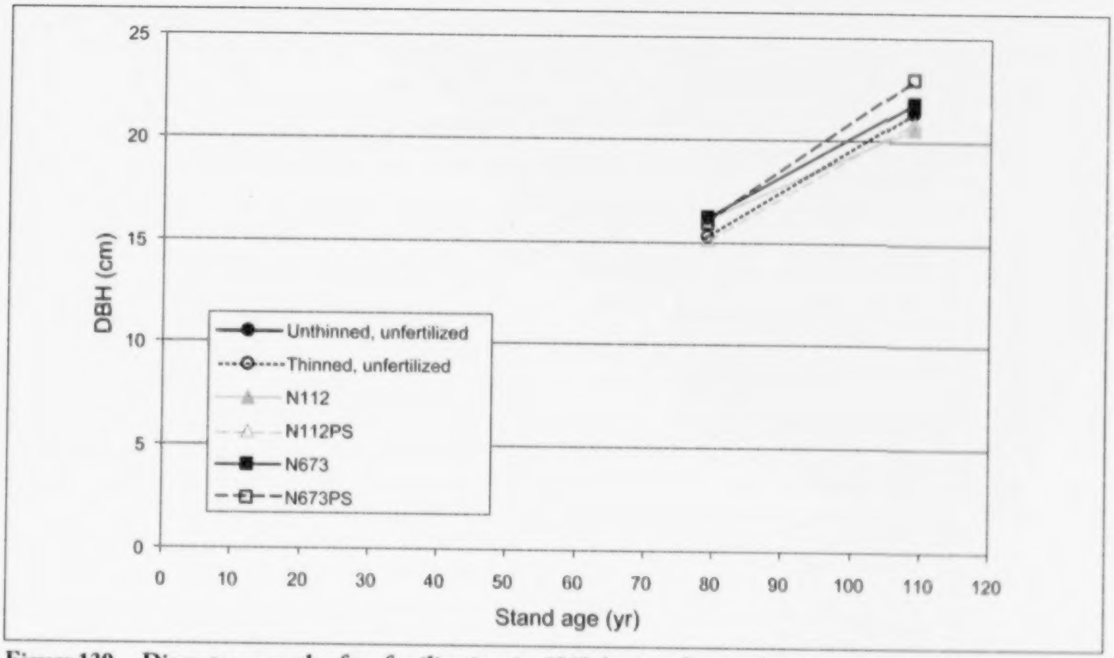

Figure 130. **Diameter growth after fertilization in 1968 (at stand age of 72 years) at the Clearwater site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]). DBH = diameter at breast height.

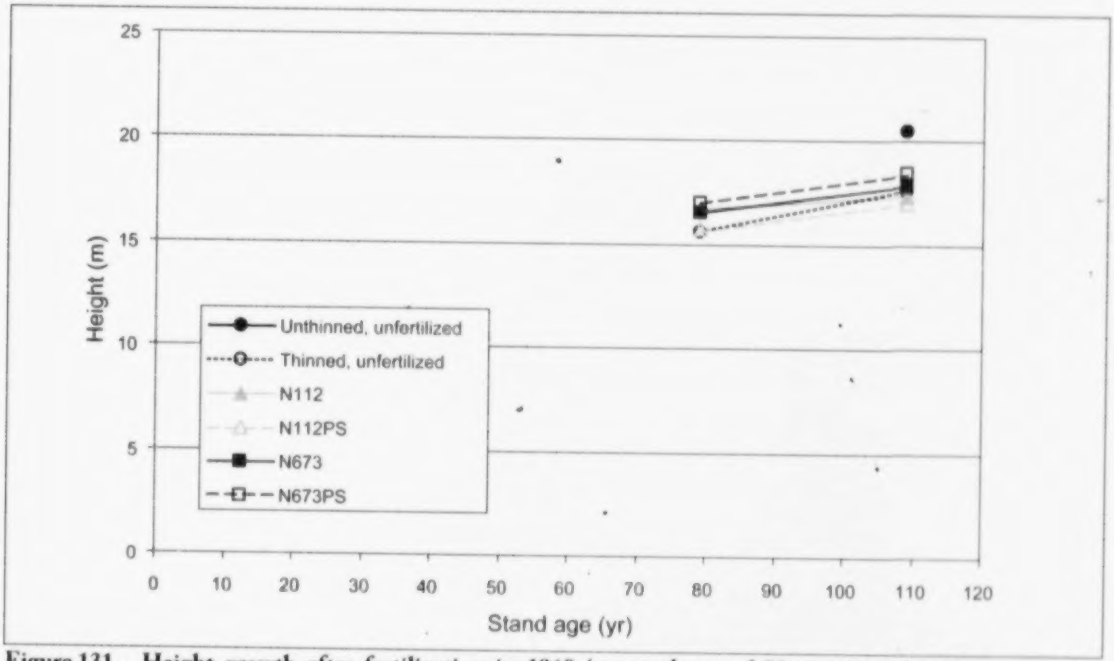

Figure 131. **Height growth after fertilization in 1968 (at stand age of 72 years) at the Clearwater site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]).

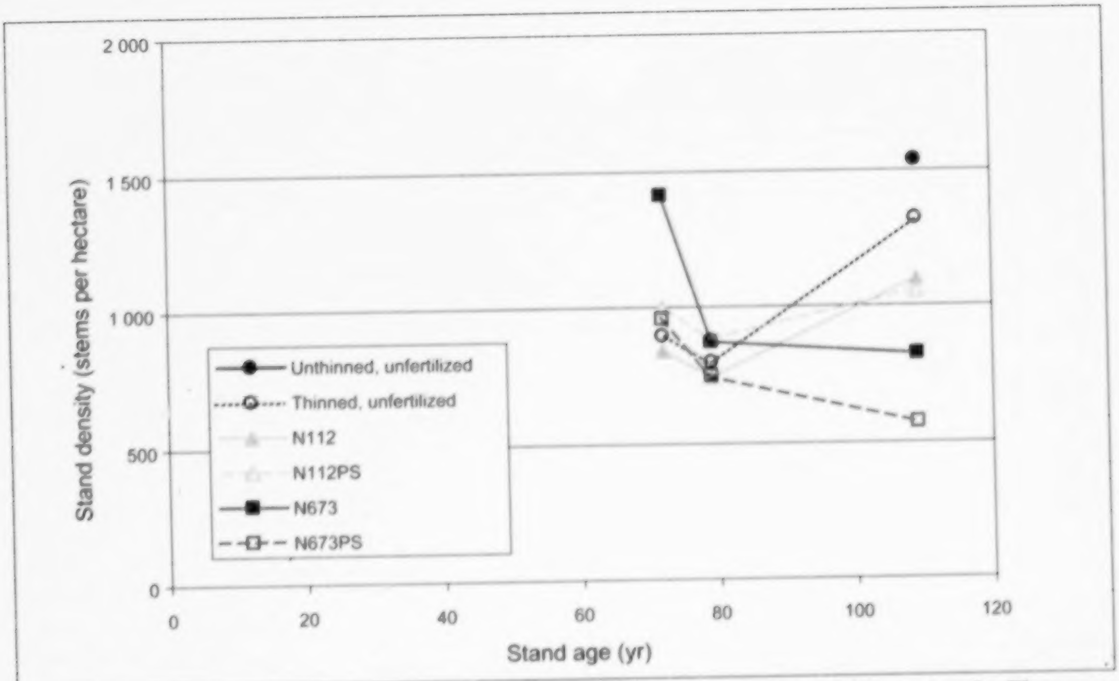

Figure 132. Stand density development after fertilization in 1968 (at stand age of 72 years) at the Clearwater site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]). DBH = diameter at breast height.

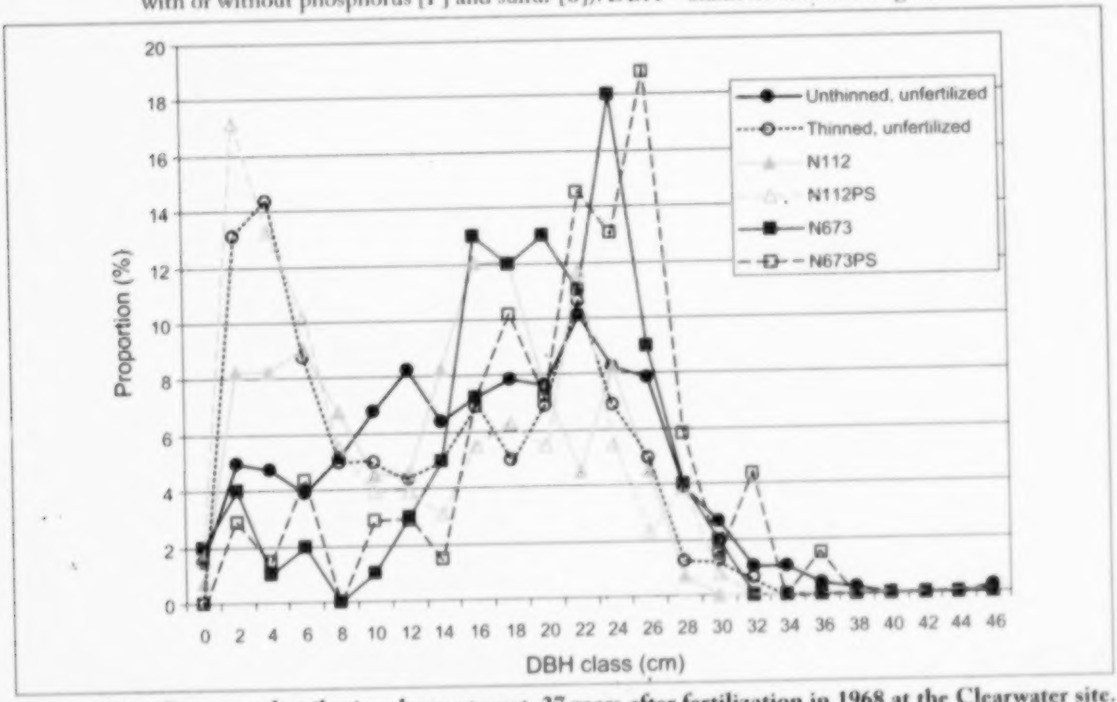

Figure 133. Diameter distribution, by treatment, 37 years after fertilization in 1968 at the Clearwater site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]). DBH = diameter at breast height.

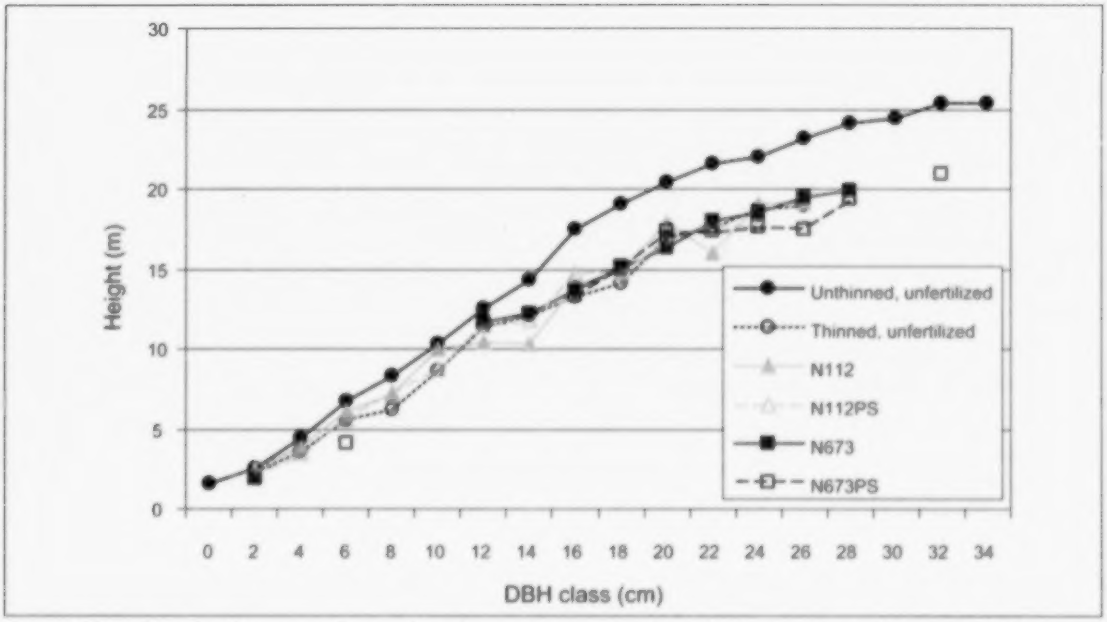

Figure 134. **Height–diameter relationships, by treatment, 37 years after fertilization in 1968 at the Clearwater site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]). DBH = diameter at breast height.

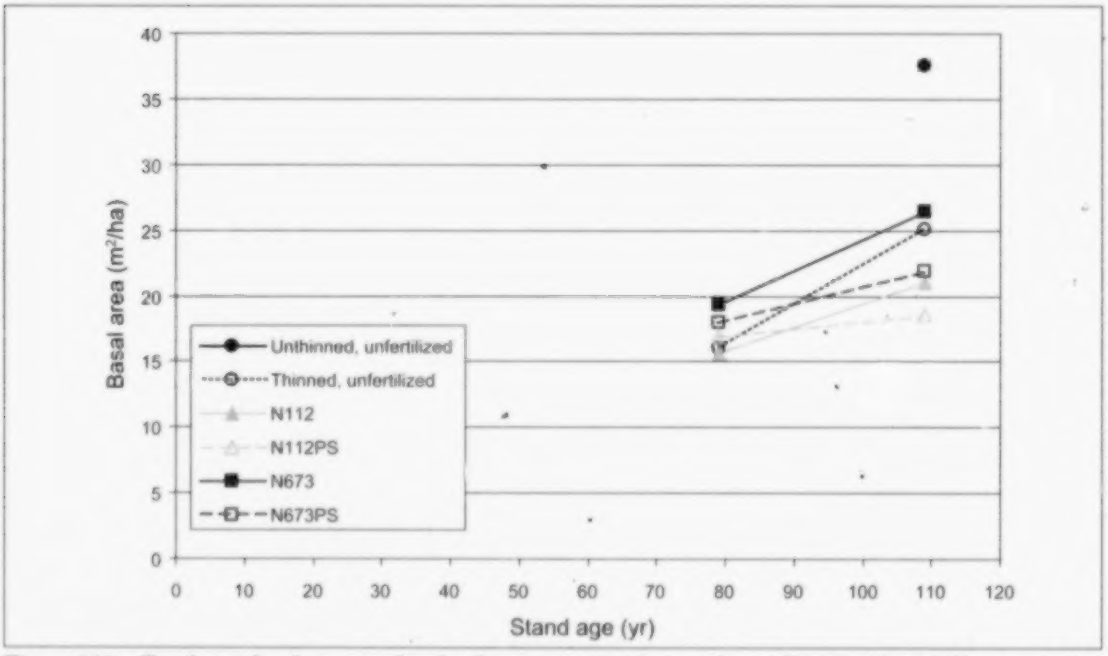

Figure 135. **Basal area development after fertilization in 1968 (at stand age of 72 years) at the Clearwater site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]).

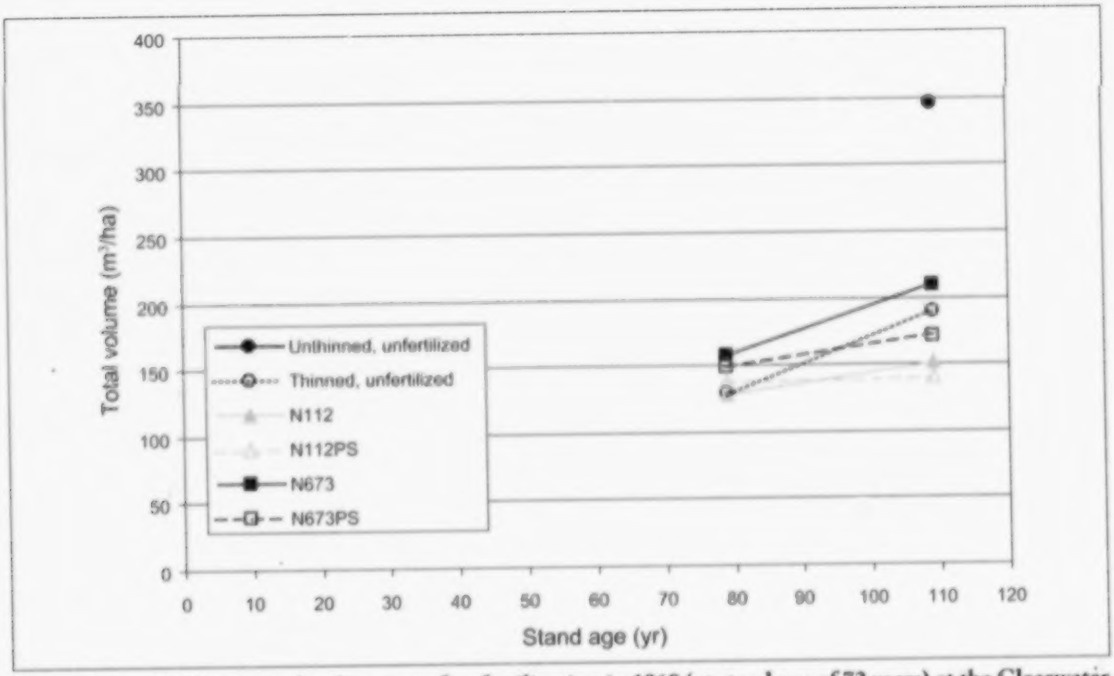

Figure 136. **Total volume development after fertilization in 1968 (at stand age of 72 years) at the Clearwater site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]).

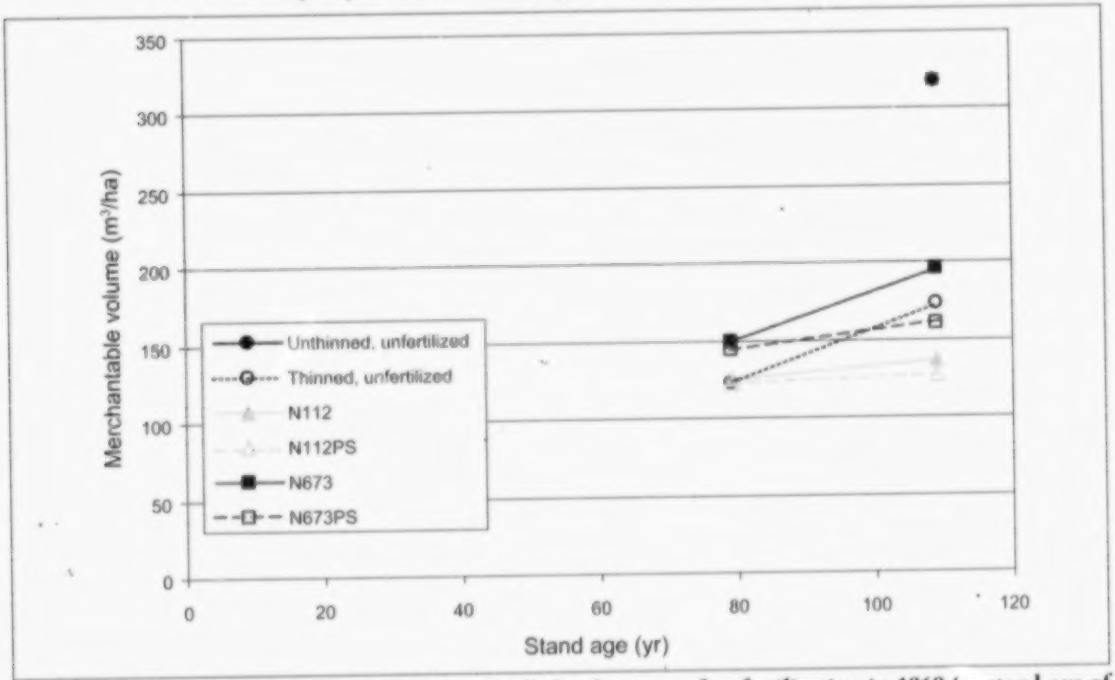

Figure 137. **Merchantable volume (13/7 standard) development after fertilization in 1968 (at stand age of 72 years) at the Clearwater site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]).

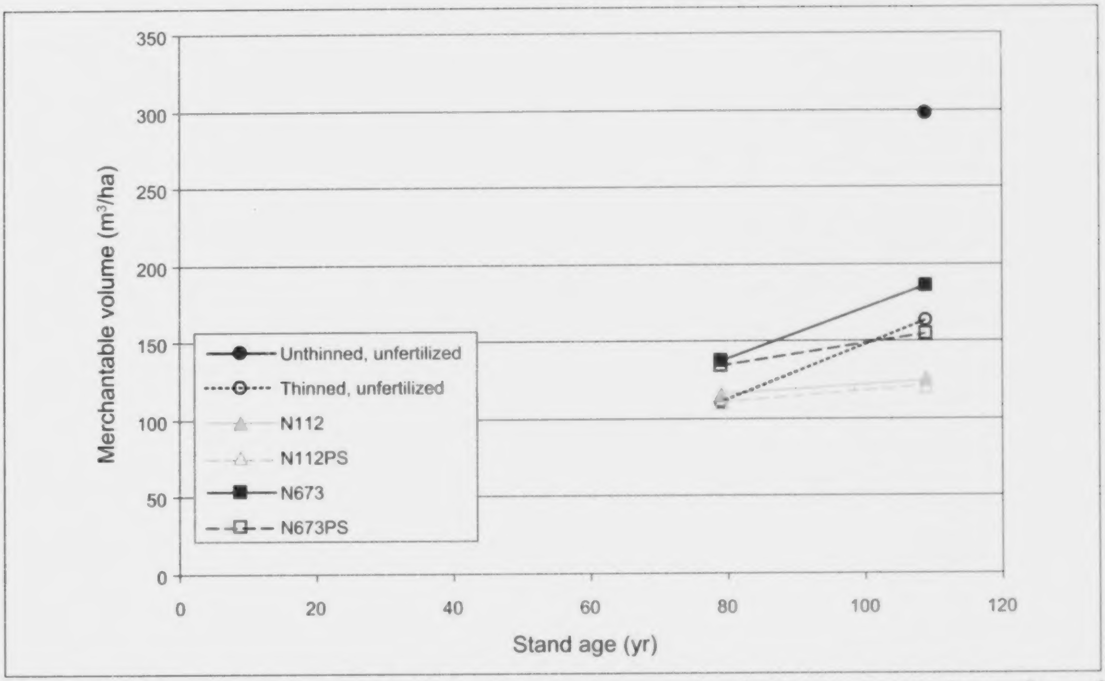

Figure 138. Merchantable volume (15/10 standard) development after fertilization in 1968 (at stand age of 72 years) at the Clearwater site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied, with or without phosphorus [P] and sulfur [S]).

Ricinus Fertilization Trial (1965)

Location and Access

The Ricinus trial site (52°03.850'N, 115°03.430'W, legal location 7/9/10-3-36-8-W5) is located in the Clearwater Valley 36 km southwest of Rocky Mountain House, Alberta. To access the site from Caroline, follow these directions:

Travel 8 km west on Highway 22 to Highway 591.

Travel 15.1 km west on Highway 591.

Look for site signage and blue boundary paint on the left side of the road.

Establishment and Objectives

The Ricinus fertilization plots were established in 1965 by I.E. Bella of the federal Department of Forestry, in a juvenile pine stand that originated after a 1949 fire. The objective of the trial was to determine whether low rates of fertilization after thinning would improve tree growth and increase stand volume. There have been no previous publications from this trial.

Site Description

The Ricinus trial site is situated in the Lower Foothills ecological subregion of southwestern Alberta, on a gently undulating plain on the floor of the Clearwater River valley. The ecological moisture regime is mesic, and the nutrient regime is medium. This site was classified in 2005 as having a C1.2 lodgepole pine/bog cranberry plant community.

Experimental Design and Treatments

The Ricinus thinning and fertilization trial was set up as a nonrandomized complete-block design with two levels of fertilization and unfertilized controls. In May 1965, the trial site was thinned to 2.1-m spacing (from 12 972 stems per hectare to 2125 stems per hectare). In 1966, six 0.04-ha plots were created, with a total of 500 trees. In October, 27-14-0 fertilizer was applied at 146 kg/ha or 291 kg/ha. These fertilization rates are equivalent to 39 kg/ha N with 20 kg/ha P and 79 kg/ha N with 41 kg/ha P, respectively. Two replicate blocks were established, with the three treatment and control plots laid out systematically.

All live trees in the treatment and control plots were tagged and measured in 1966, 1975, 1996, and 2005. Data summaries only are available for 1966. Heights were subsampled in 1975, but all heights were measured thereafter. In 2005, height to live crown and crown radius were also measured.

Results after 39 years

The results presented here are based on the data collected in 1975 and 2005.

Tree Growth and Mortality

Mortality was very low across all treatments for the 30-year measurement interval (Fig. 139). The control plots had the greatest mortality of crop trees (17%). The higher N treatment had a 12.5% loss of crop trees, and the lower N treatment had a loss of only 8.9%.

Diameter growth and height growth across all three treatments were relatively uniform over the period (Figs. 140 and 141). All treatments had approximately 7 cm diameter growth over the 30 years between measurements, with only 1.7 cm separating the low N treatment (greatest average diameter growth) and the unfertilized control (least average diameter growth) in 2005. Differences in height growth were smaller, with only 0.2 m in height separating the fertilization treatments after 30 years. Height growth in the unfertilized control was identical with that for the low N treatment.

Stand Development

Stem densities in the unfertilized control and the N39P20 treatment plots remained almost unchanged over the 30-year study period (Fig. 142). The N79P41 treatment showed the greatest change, with a mortality loss of 150 stems per hectare. Ingrowth was not significant in any of the plots.

There was little difference between treatments in terms of diameter distribution; trees in the N39P20 treatment had slightly larger average diameter than those in the N79P41 treatment, and the latter was nearly identical with that of the unfertilized control trees (Fig. 143). Fertilization did not seem to affect stem slenderness, and all treatments followed the same height–diameter curve (Fig. 144).

Over the 30-year study period, basal area in the unfertilized control plot grew 0.98 m^2/ha more than in the high N treatment plot and 0.06 $m^2\ ha^{-1}\ yr^{-1}$ faster than in the low N treatment plot (Fig. 145). These differences appear to be driven largely by differences in stand density.

Total volume was greatest in the unfertilized control plot, as was the increase in total volume (Fig. 146). In the unfertilized control plot, total volume increased by approximately 7 m^3/ha annually, whereas total volume increment was approximately 6.7 $m^3\ ha^{-1}\ yr^{-1}$ and 6.2 $m^3\ ha^{-1}\ yr^{-1}$ for the N79P41 and N39P20 treatments, respectively. The same patterns were reflected in the merchantable volumes (Figs. 147 and 148), with the exception of the 15/10 merchantable volume in the lower N treatment plot, which was the same as for the unfertilized control.

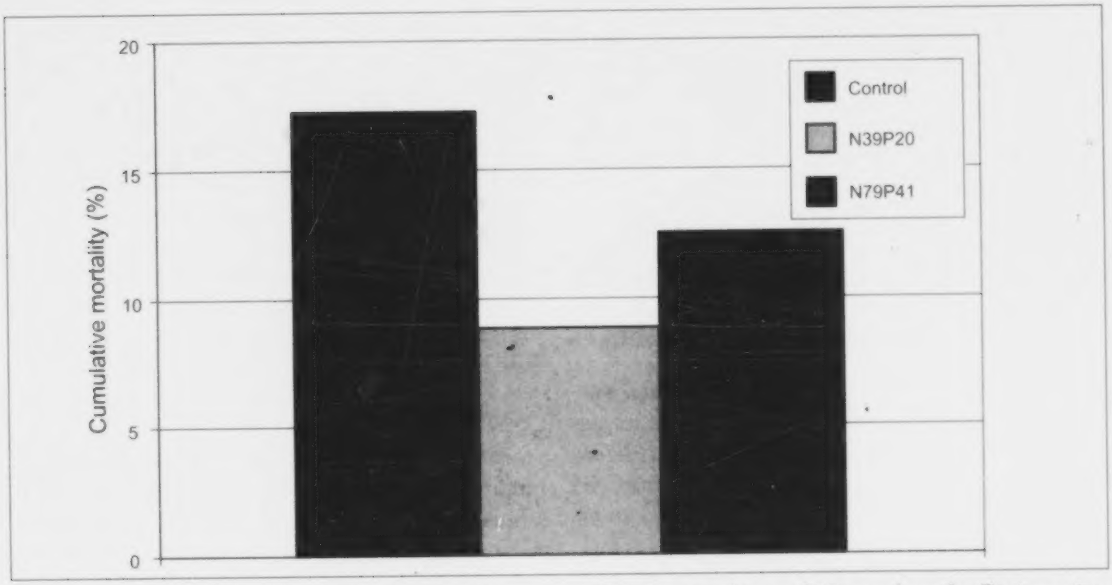

Figure 139. **Cumulative mortality after fertilization in 1966 (at stand age of 17 years) at the Ricinus site.** Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied).

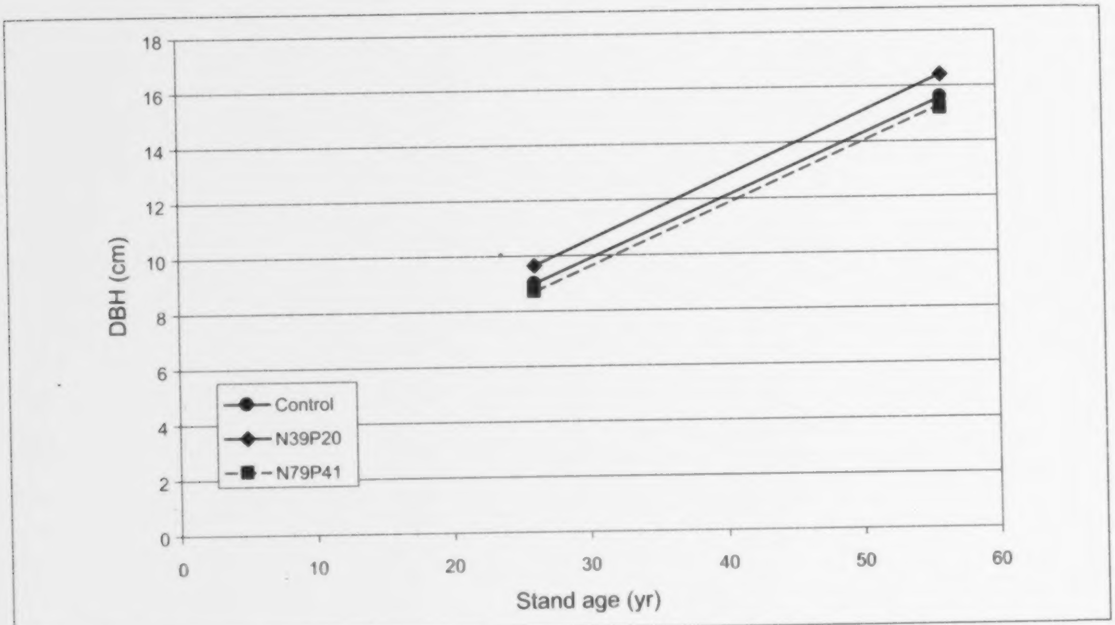

Figure 140. **Diameter growth after fertilization in 1966 (at stand age of 17 years) at the Ricinus site.** Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

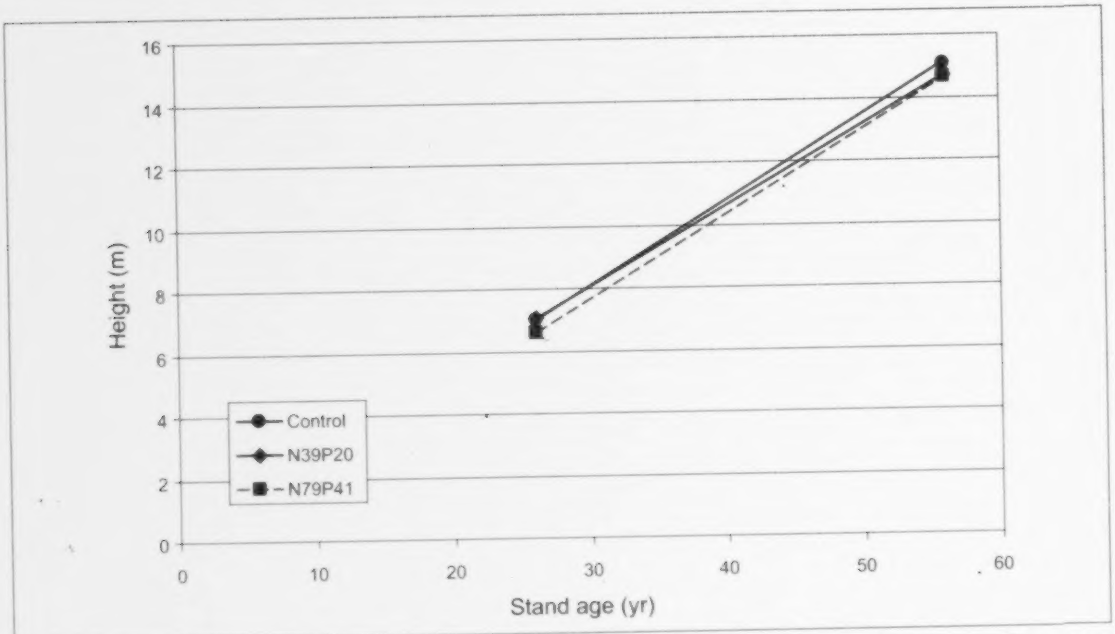

Figure 141. **Height growth after fertilization in 1966 (at stand age of 17 years) at the Ricinus site.** Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied).

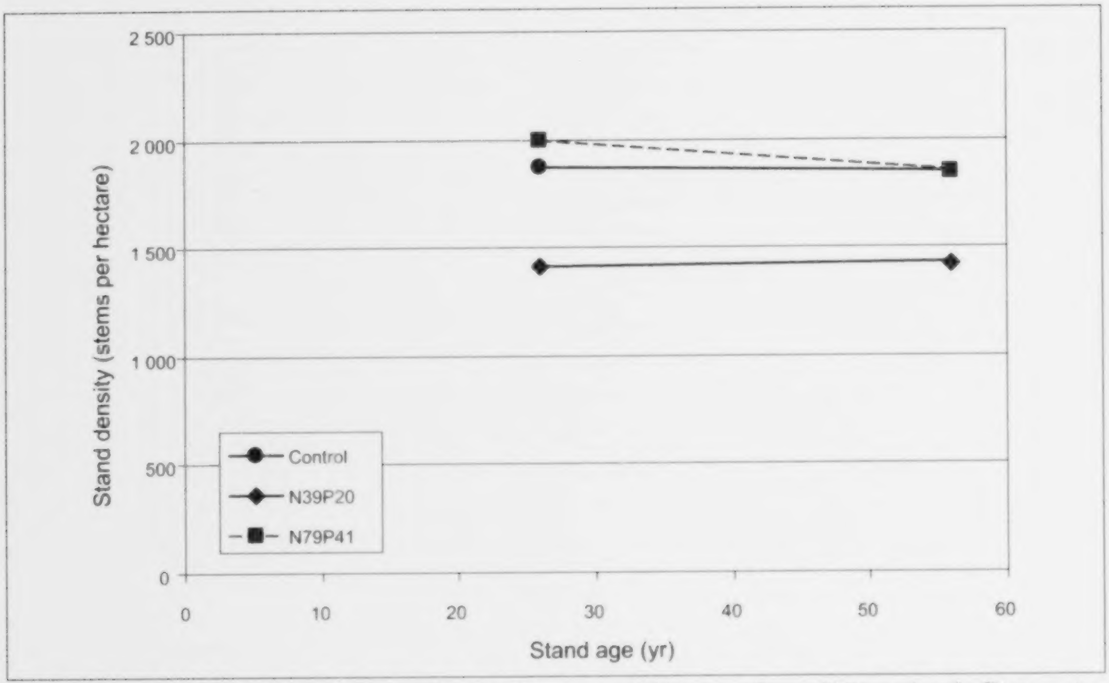

Figure 142. **Stand density development after fertilization in 1966 (at stand age of 17 years) at the Ricinus site.** Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

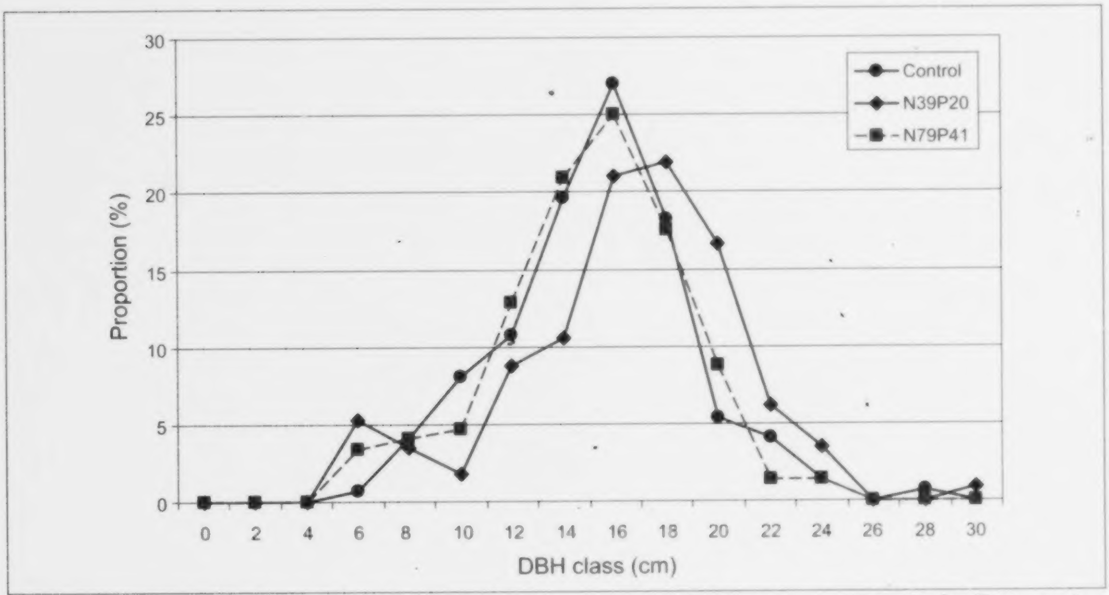

Figure 143. **Diameter distribution, by treatment, 39 years after fertilization in 1966 at the Ricinus site.** Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

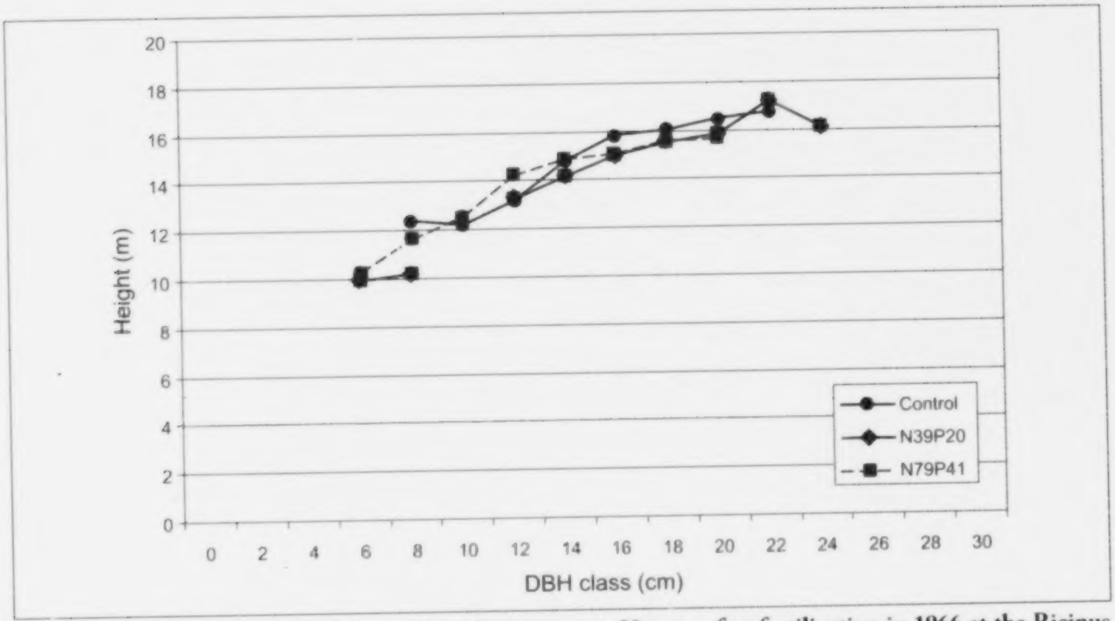

Figure 144. **Height–diameter relationships, by treatment, 39 years after fertilization in 1966 at the Ricinus site.** Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

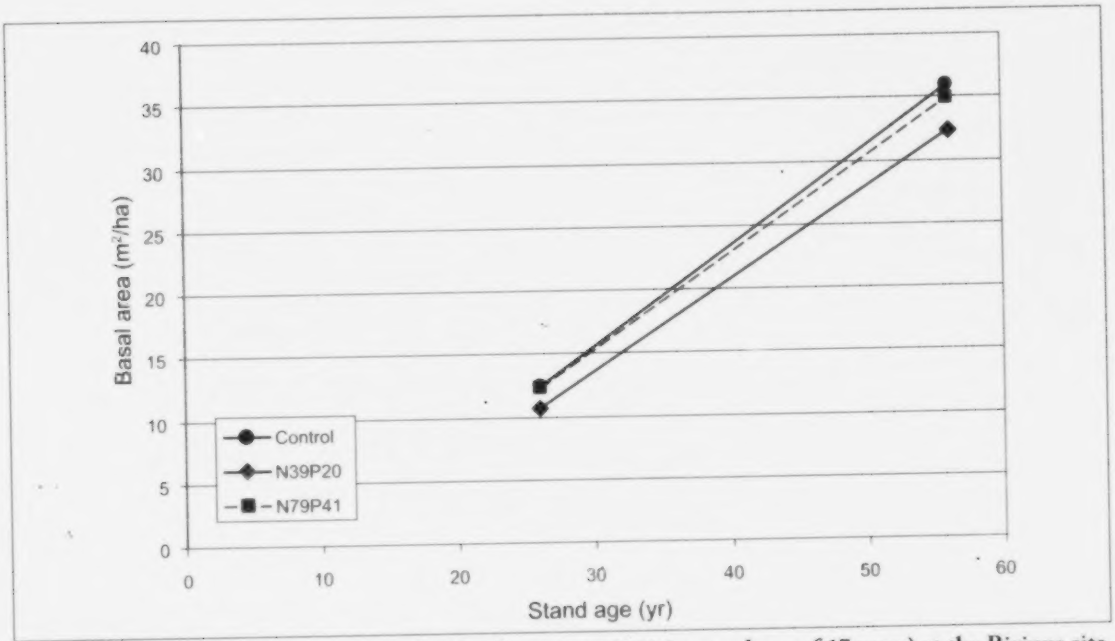

Figure 145. **Basal area development after fertilization in 1966 (at stand age of 17 years) at the Ricinus site.** Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied).

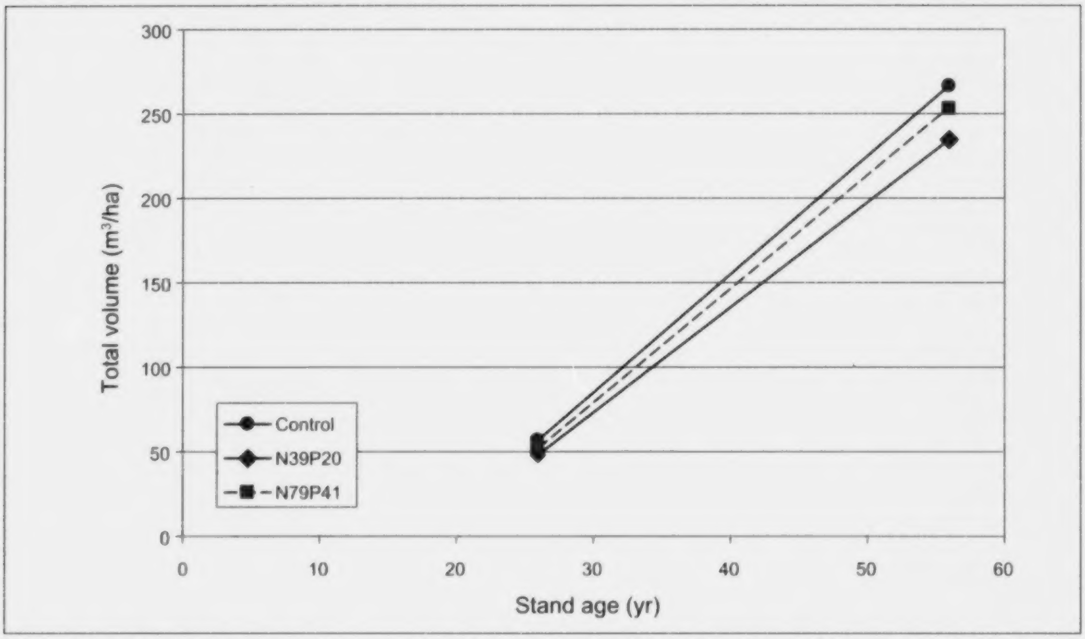

Figure 146. Total volume development after fertilization in 1966 (at stand age of 17 years) at the Ricinus site. Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied).

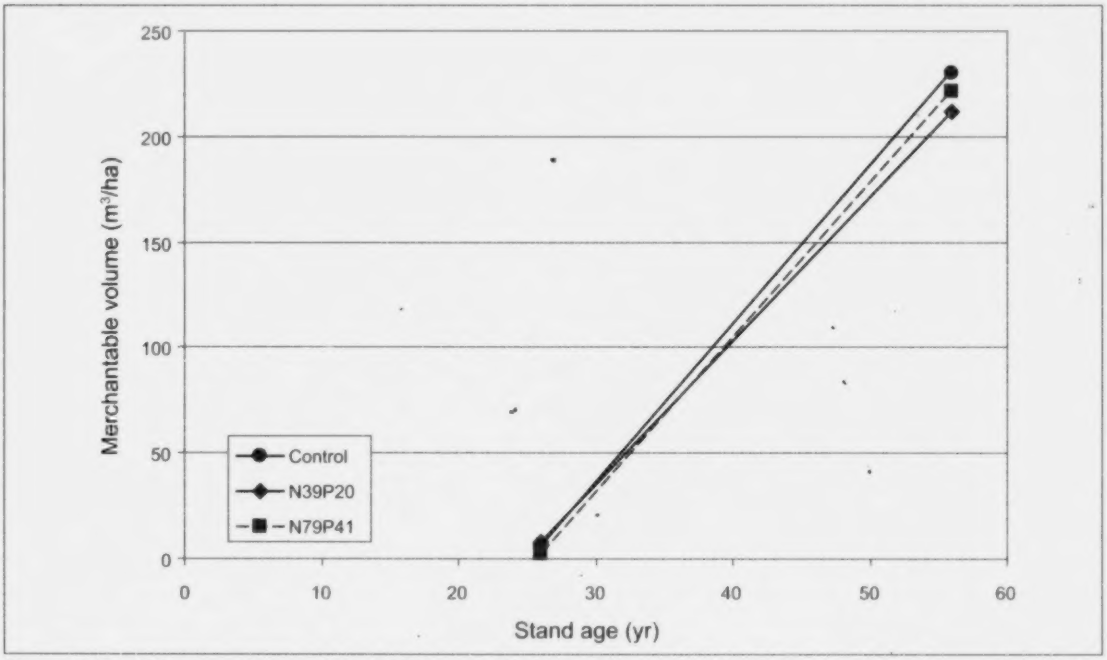

Figure 147. Merchantable volume (13/7 standard) development after fertilization in 1966 (at stand age of 17 years) at the Ricinus site. Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied).

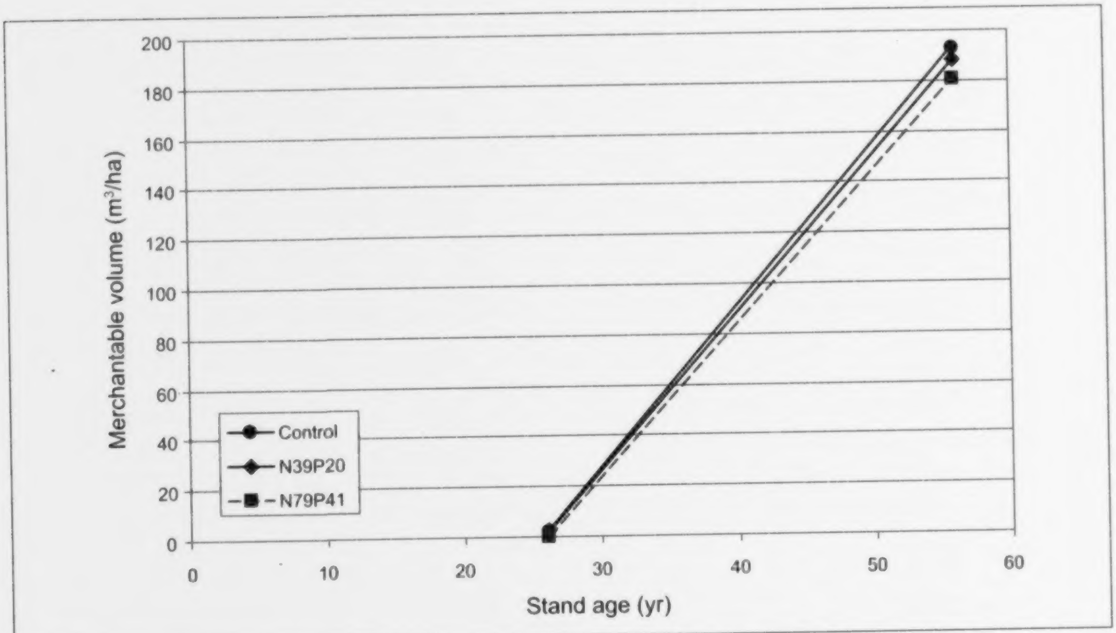

Figure 148. Merchantable volume (15/10 standard) development after fertilization in 1966 (at stand age of 17 years) at the Ricinus site. Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied).

McCardell Creek Road Fertilization and Thinning Experiment (1984)

Location and Access

The McCardell experiment site (53°11.8'N, 117°11.1'W, legal location 3/6/7/8-5-49-22-W5) is located 50 km southeast of Hinton. To access the McCardell site from Hinton, follow these directions:

From Switzer Drive, access the Robb Road.

Turn south on the Robb Road and travel for 31.8 km to the Pembina River Road.

Turn right (south) on the Pembina River Road and travel 10.7 km to an unmarked logging road (known as the McCardell Creek road).

Turn right (west) on the McCardell Creek road and travel 1.5 km to a truck trail that angles back sharply to the left.

Walk 300 m up the trail and watch for signage and boundary paint.

Establishment and Objectives

The McCardell fertilization and thinning experiment was established in 1984 by R.C. Yang of the Canadian Forestry Service in a densely stocked, 40-year-old, fire-origin lodgepole pine stand. The objectives of the experiment were to ascertain the foliage response of semimature lodgepole pine to combined thinning and fertilization treatments and examine relationships between foliar response and subsequent stand growth, to assess the effects of fertilization and thinning (singly and in combination) on growth and mortality, and to determine the optimum fertilizer regimen for lodgepole pine on the soil type studied. A paper by Yang (1998) is the only previous publication from this experiment.

Site Description

The McCardell experiment site is in the Upper Foothills ecological subregion of west-central Alberta, located on a site of level to gently undulating topography (4–11% grade). Soils are well-drained Podzolic Grey Luvisols (Yang 1998). The moisture regime is mesic, and the ecological nutrient regime is poor to medium (Ecotope Consulting Services 1999). This site was classified in 2004 as having an E1.3 lodgepole pine/Labrador tea/feather moss plant community.

Experimental Design and Treatments

The McCardell experiment has a randomized split-plot complete-block design with factorial arrangement of the fertilization and thinning treatments. Nine replicate blocks (60 m × 80 m) were established, each divided into two sub-blocks for thinned and unthinned treatments. Each sub-block contained four circular fertilization plots with radius 9.5 m. A measurement plot with radius 6.9 m was nested inside each fertilization plot. Plot centers were 20 m apart, providing a minimum of 5 m buffer between plot edges. Thinning of the sub-blocks was carried out by hand in summer 1984 to reduce stand basal area to 26 m^2/ha or about 2100 stems per hectare. In November, N (as ammonium nitrate fertilizer) was applied to plots at three levels: 180, 360, and 540 kg/ha; control plots were left unfertilized. In addition, 40 kg/ha of P (as ammonium phosphate) and of S (as ammonium sulfate) were applied to every fertilized plot.

All live trees within the measurement plots were tagged, and their diameter was measured. Height was measured on 10 dominant or codominant trees in each plot. Measurements were taken in 1984, 1989, 1994, 1999, and 2004. In 2004, diameter, height, height to live crown, and crown radius were measured for all live trees.

Results after 20 Years

Tree Growth and Mortality

Mortality of crop trees showed a consistent pattern across thinning and fertilization treatments. Mortality was high in the first 5 years (more than 3–5% per year for unthinned treatments) and declined in both of the next two measurement periods (Fig. 149). Mortality increased again between 15 and 20 years after treatment. The unthinned treatments had noticeably more mortality than the thinned treatments across the study period, regardless of level of fertilization. Mortality was greatest for the N540 treatment in both thinned and unthinned plots, and the unfertilized treatment had the lowest mortality in the thinned plots; otherwise fertilization had little effect on mortality.

Although trees in the thinned plots had higher starting diameters, diameter growth was similar across both thinned and unthinned plots over the entire study period, with two major exceptions (Figs. 150). In the unthinned plots, the 360 kg/ha N treatment consistently yielded greater diameters than the other fertilization treatments. In contrast, in the thinned plots, trees in all of the fertilized treatments had approximately the same diameters, about 1 cm greater than those without added N.

There was little difference in height growth regardless of thinning or fertilization (Fig. 151). The decline in rate of height growth in the most recent 5-year interval could be related to observed mortality disproportionately affecting taller trees and/or original trees not fully representing the height growth of the population of trees included in the latest measurement.

Stand Development

Stand densities in the unthinned plots declined rapidly over the study period (a loss of approximately 50%), with one episode of little or no mortality between 1994 and 1999 (Fig. 152A). The thinned plots, on the other hand, lost only about 20% of their stems (Fig. 152B). Fertilization seemed to have little impact on density. Thinning had a small effect on diameter distributions, with trees in the unthinned plots having slightly smaller diameters; otherwise, the diameter distributions for the different fertilization treatments overlapped closely (Fig. 153). Neither thinning nor fertilization seemed to have any effect on the height–diameter relationship (Fig. 154).

Although basal area was larger in the unthinned plots than in the thinned plots, the basal area in the thinned plots grew faster (0.70 m^2 ha^{-1} yr^{-1} and 0.45 m^2 ha^{-1} yr^{-1} for thinned and unthinned plots, respectively) (Fig. 155). In both thinned and unthinned plots, basal area seemed to peak at stand age of 55 years and then declined over the next 5 years, because of the high mortality measured in 2004. Basal area was not significantly affected by N treatments.

Similar to what was observed for basal area, total volume was greater in the unthinned plots, but volume increased slightly faster in the thinned plots (Fig. 156). Among the unthinned plots, the 540 kg/ha N treatment had the greatest volume up to 1999; however, this treatment also exhibited the greatest decline through 2004. Among the thinned plots, volume growth for all of the fertilization treatments was about the same; it slowed (but did not decline) after 1999. The 360 kg/ha N treatment had the largest total volume by 2004, after exhibiting slightly higher growth rates throughout the study period.

Thinning had minimal effect on merchantable volume (13/7 standard), and only the 360 kg/ha N fertilization appeared to increase merchantable volume above that for other treatments (Fig. 157). This effect was most noticeable in the unthinned plots, where early gains observed with the N540 treatment were lost because of mortality in the last 5 years. At the 15/10 standard, merchantable volume was also greatest for the unthinned plots with 360 kg/ha N fertilization and differed little among the other fertilization treatments (Fig. 158). Among the thinned plots, the 15/10 merchantable volumes were similar for all fertilization treatments, but the unfertilized treatment had noticeably lower merchantable volumes at this standard (in contrast to the situation for the 13/7 merchantable volume).

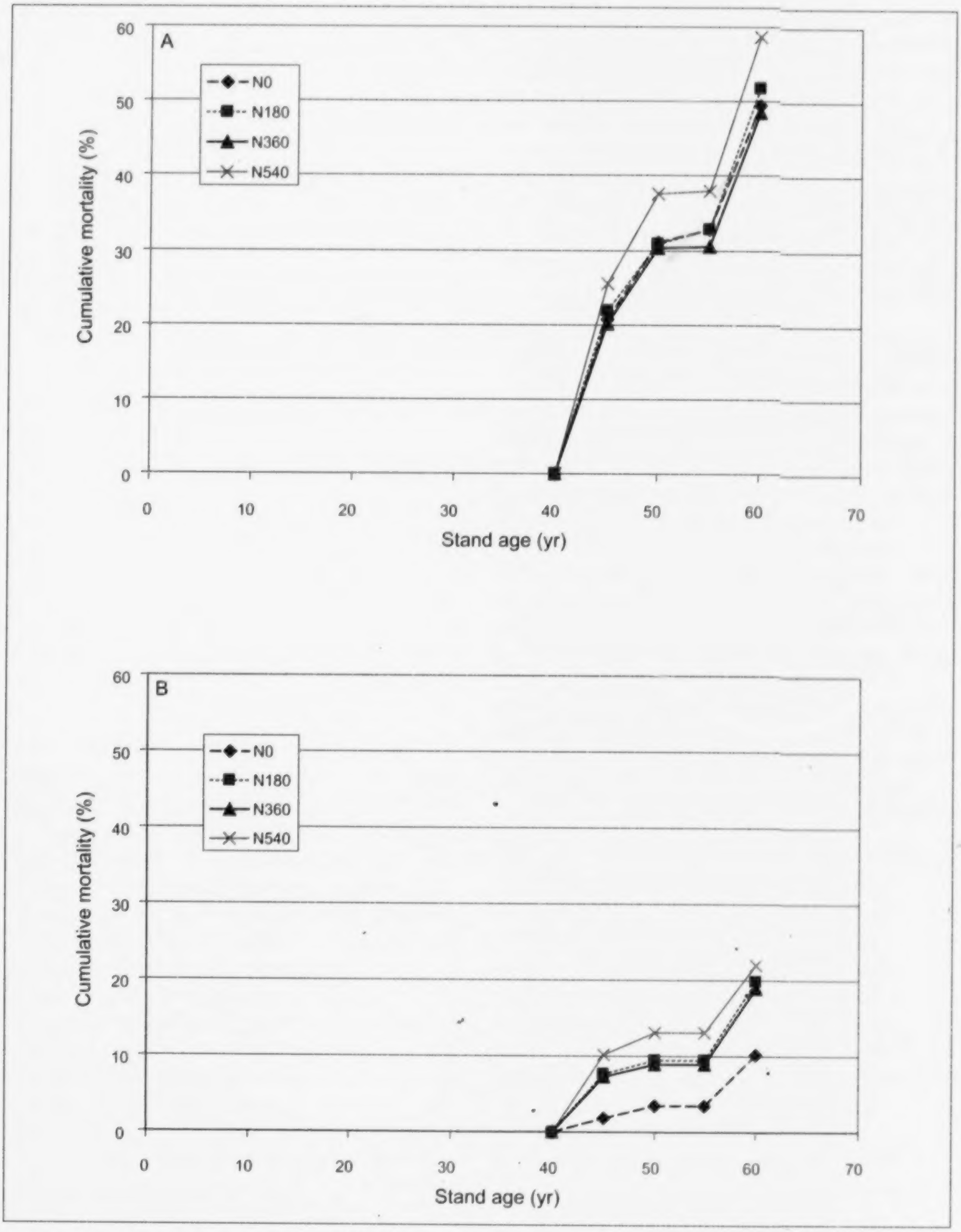

Figure 149. Cumulative mortality of (A) the unthinned and (B) the thinned plots after fertilization in 1984 (at stand age of 40 years) at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

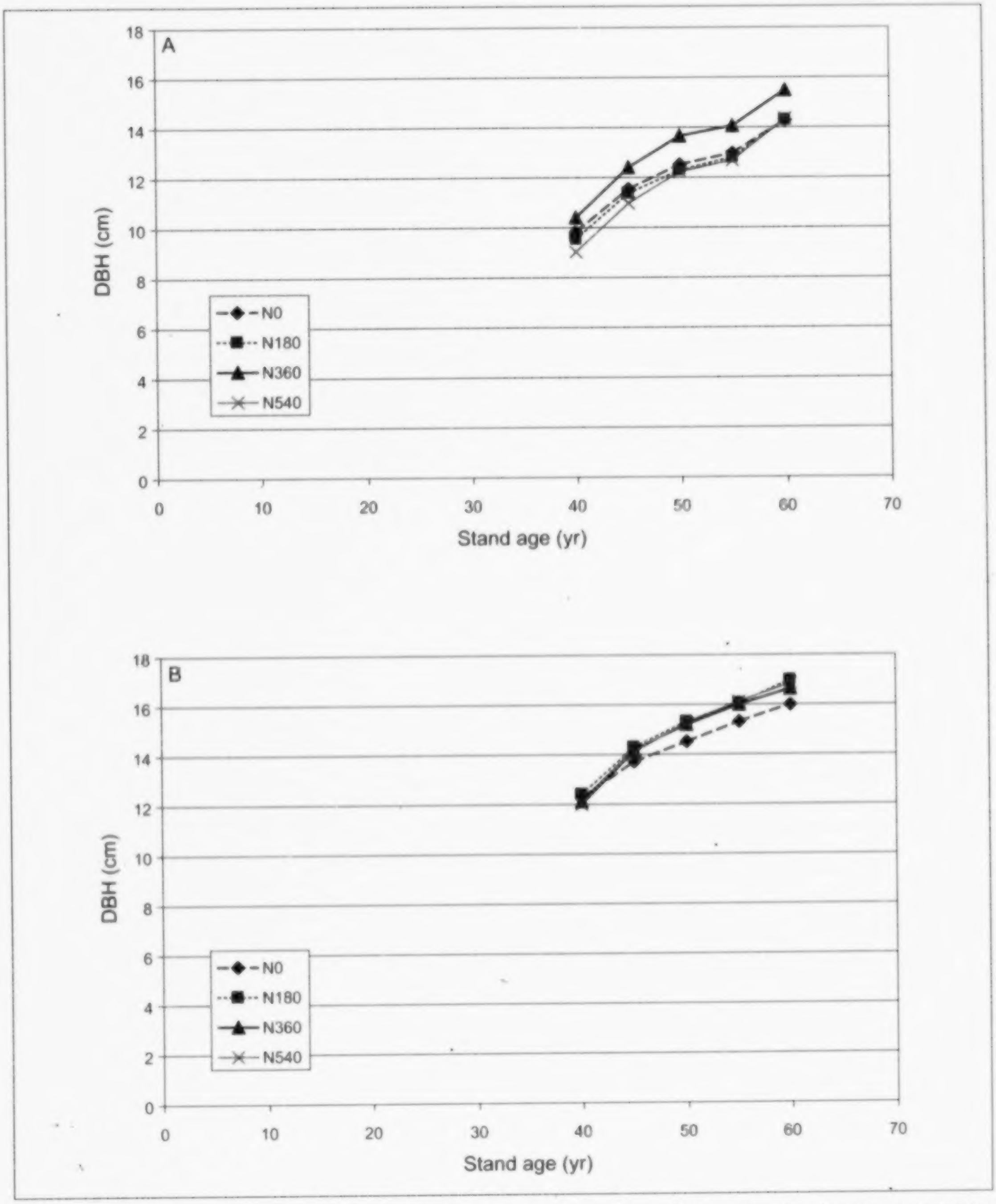

Figure 150. **Diameter growth of (A) the unthinned and (B) the thinned plots after fertilization in 1984 (at stand age of 40 years) at the McCardell site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

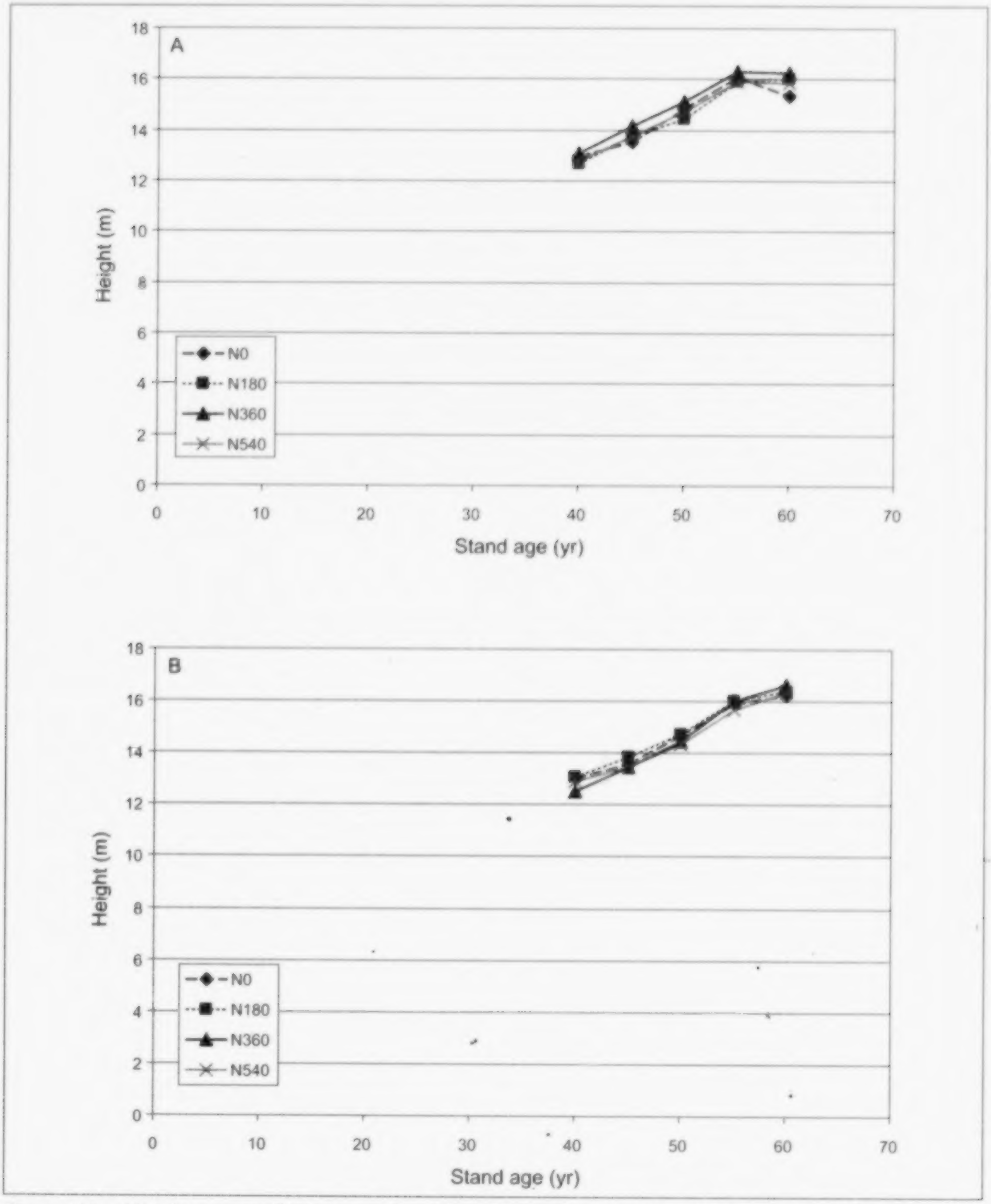

Figure 151. Height growth of (A) the unthinned and (B) the thinned plots after fertilization in 1984 (at stand age of 40 years) at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

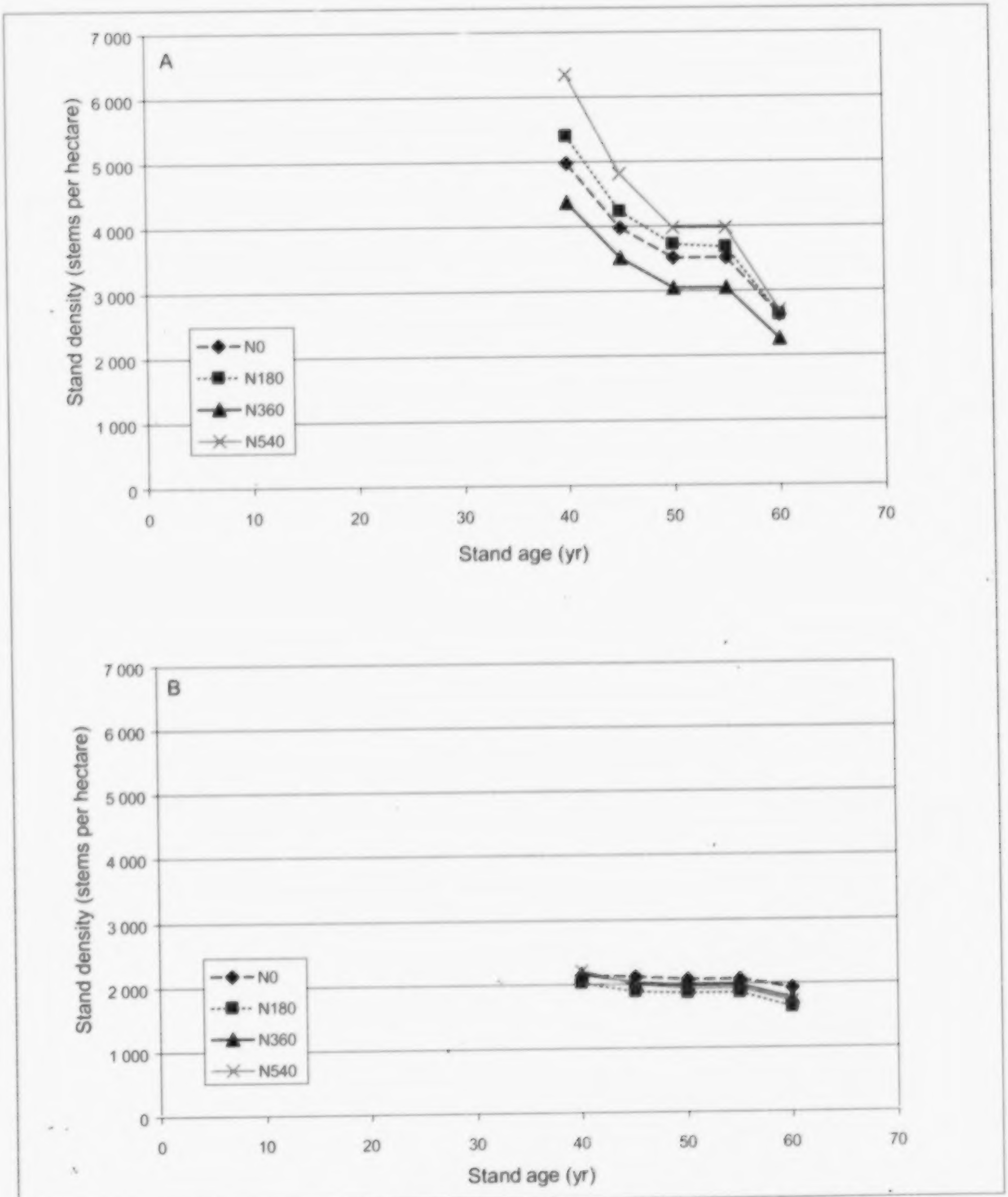

Figure 152. Stand density development of (A) the unthinned and (B) the thinned plots after fertilization in 1984 (at stand age of 40 years) at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied). .

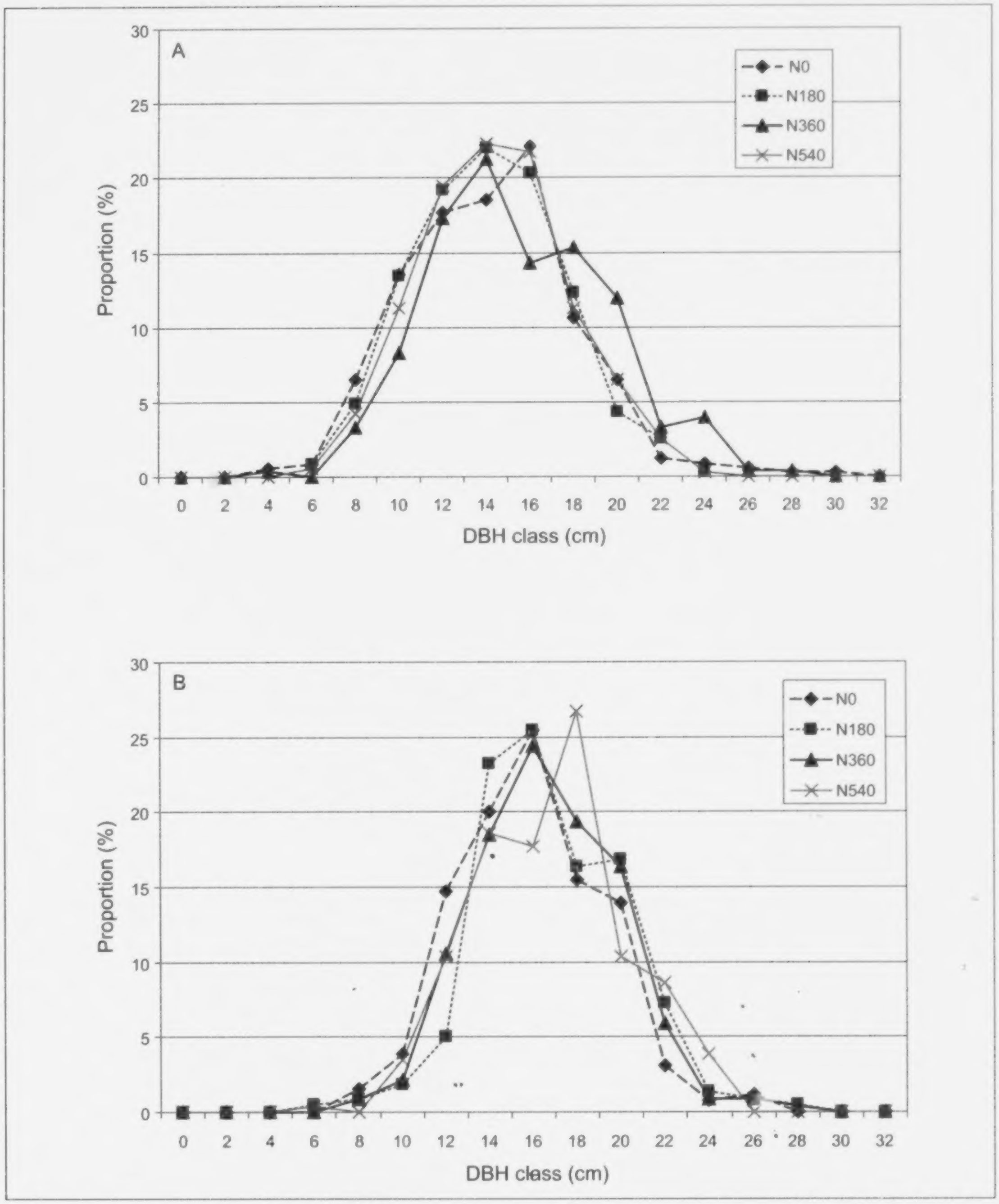

Figure 153. Diameter distribution of (A) the unthinned and (B) the thinned plots, 20 years after fertilization in 1984 at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

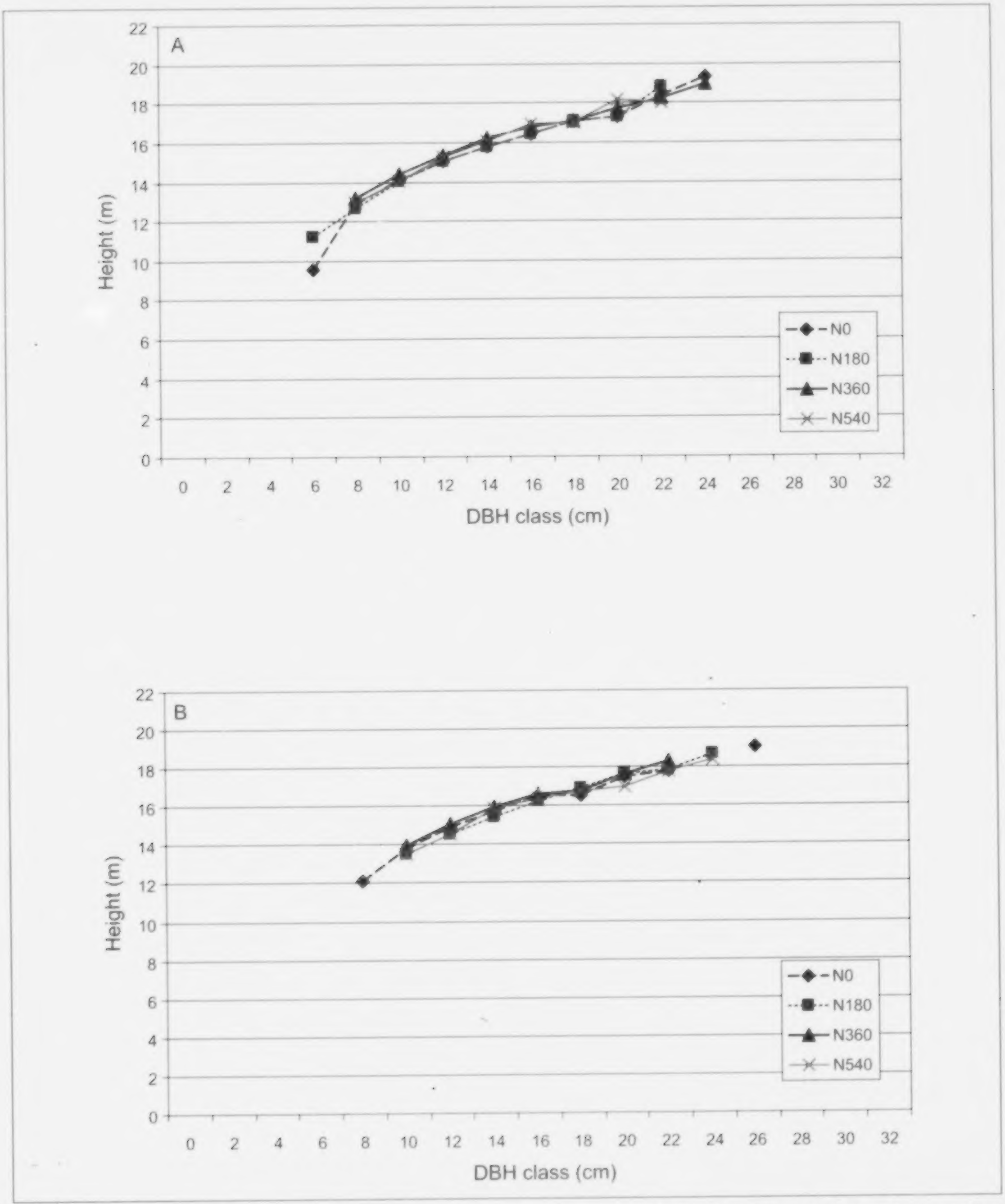

Figure 154. Height–diameter relationships of (A) the unthinned and (B) the thinned plots, 20 years after fertilization in 1984 at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

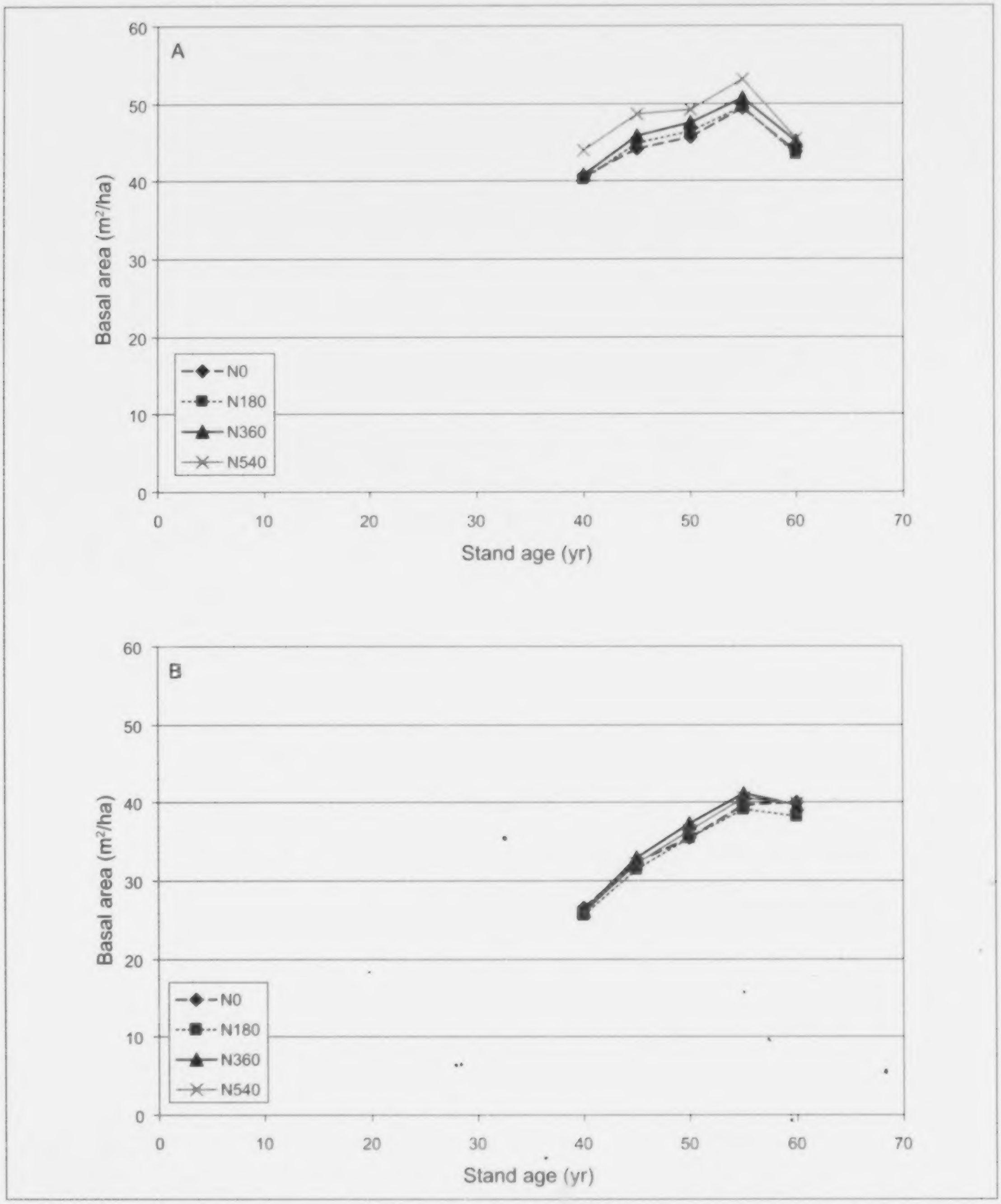

Figure 155. Basal area development of (A) the unthinned and (B) the thinned plots after fertilization in 1984 (at stand age of 40 years) at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

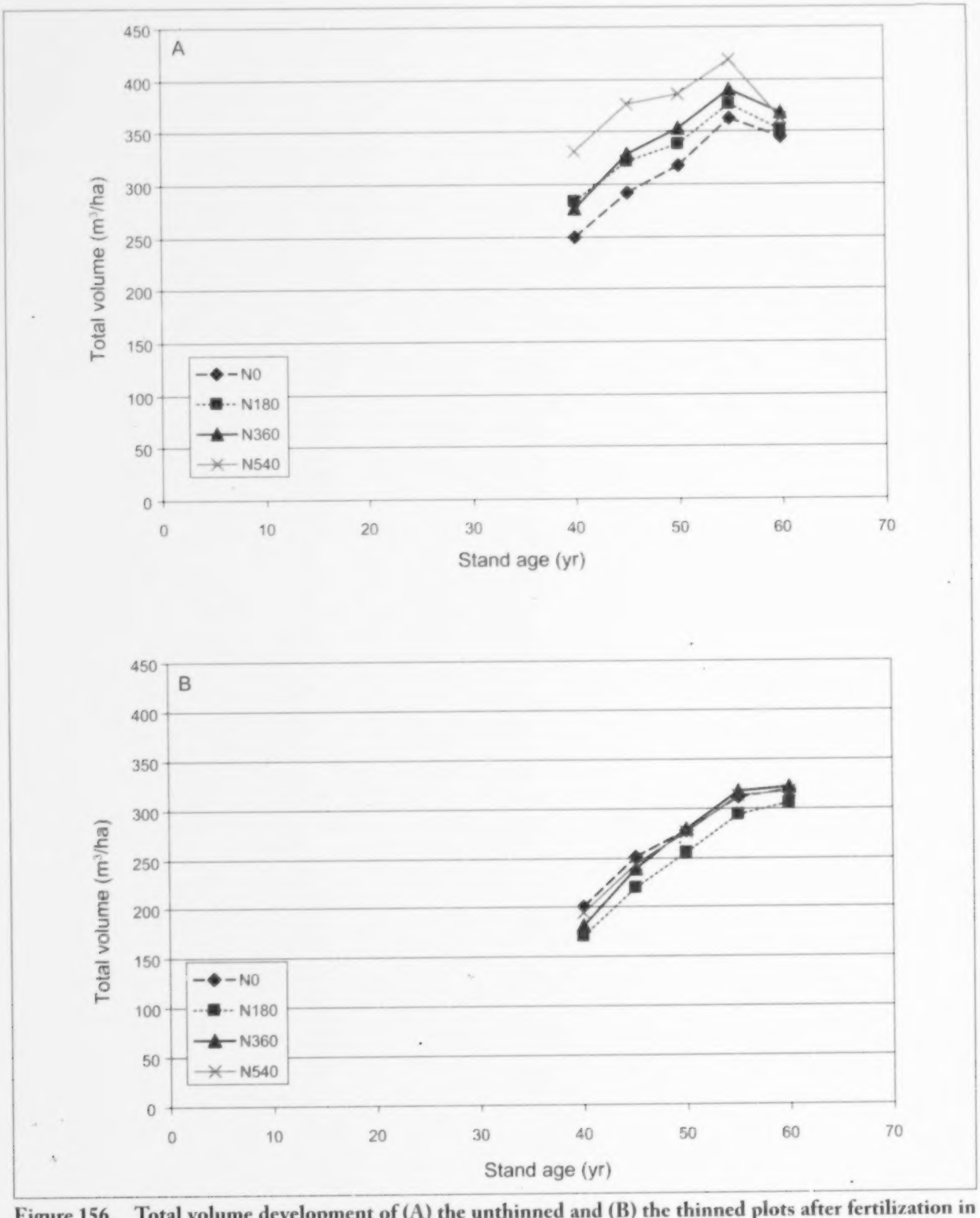

Figure 156. Total volume development of (A) the unthinned and (B) the thinned plots after fertilization in 1984 (at stand age of 40 years) at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

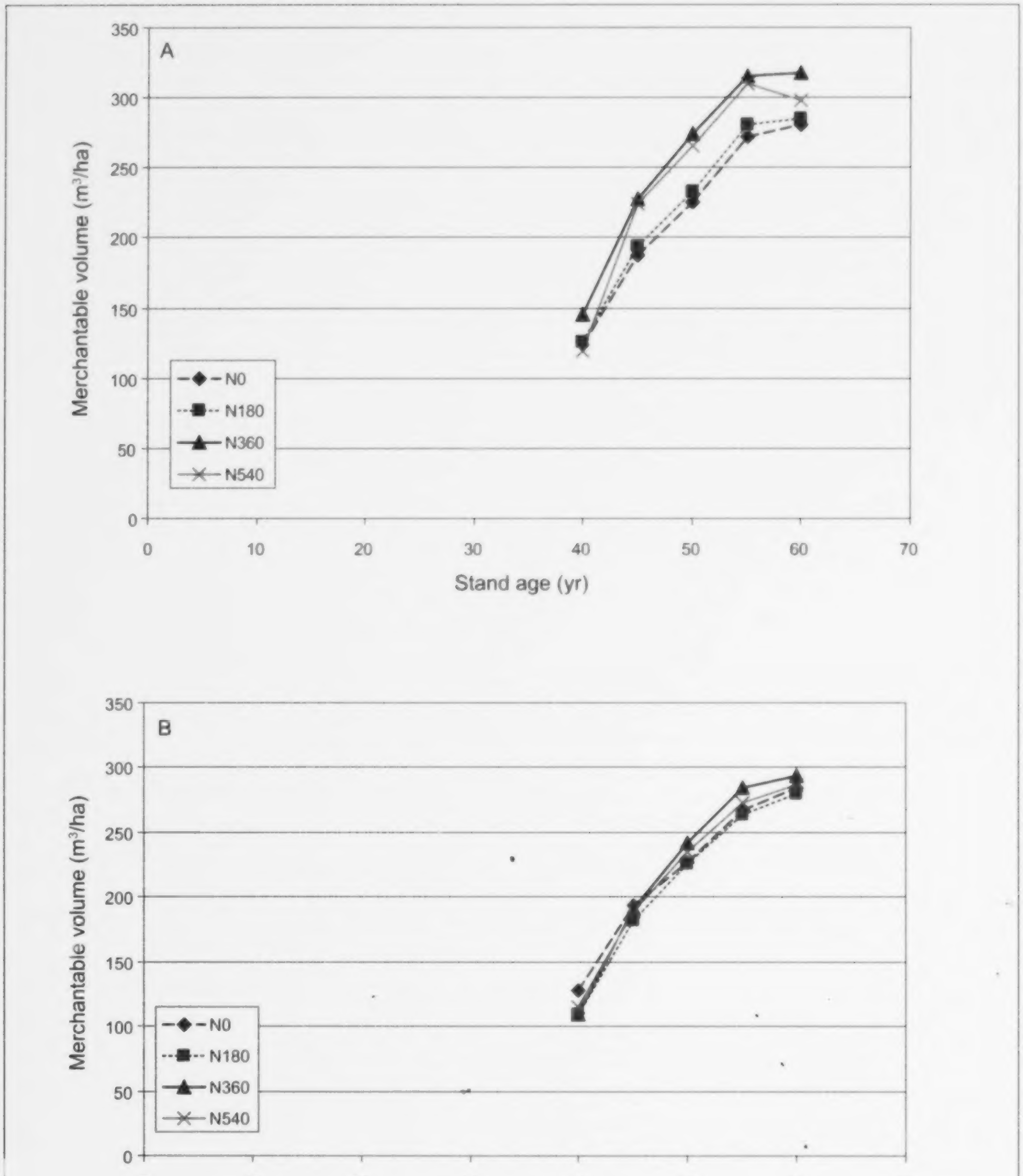

Figure 157. Merchantable volume (13/7 standard) development of (A) the unthinned and (B) the thinned plots after fertilization in 1984 (at stand age of 40 years) at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

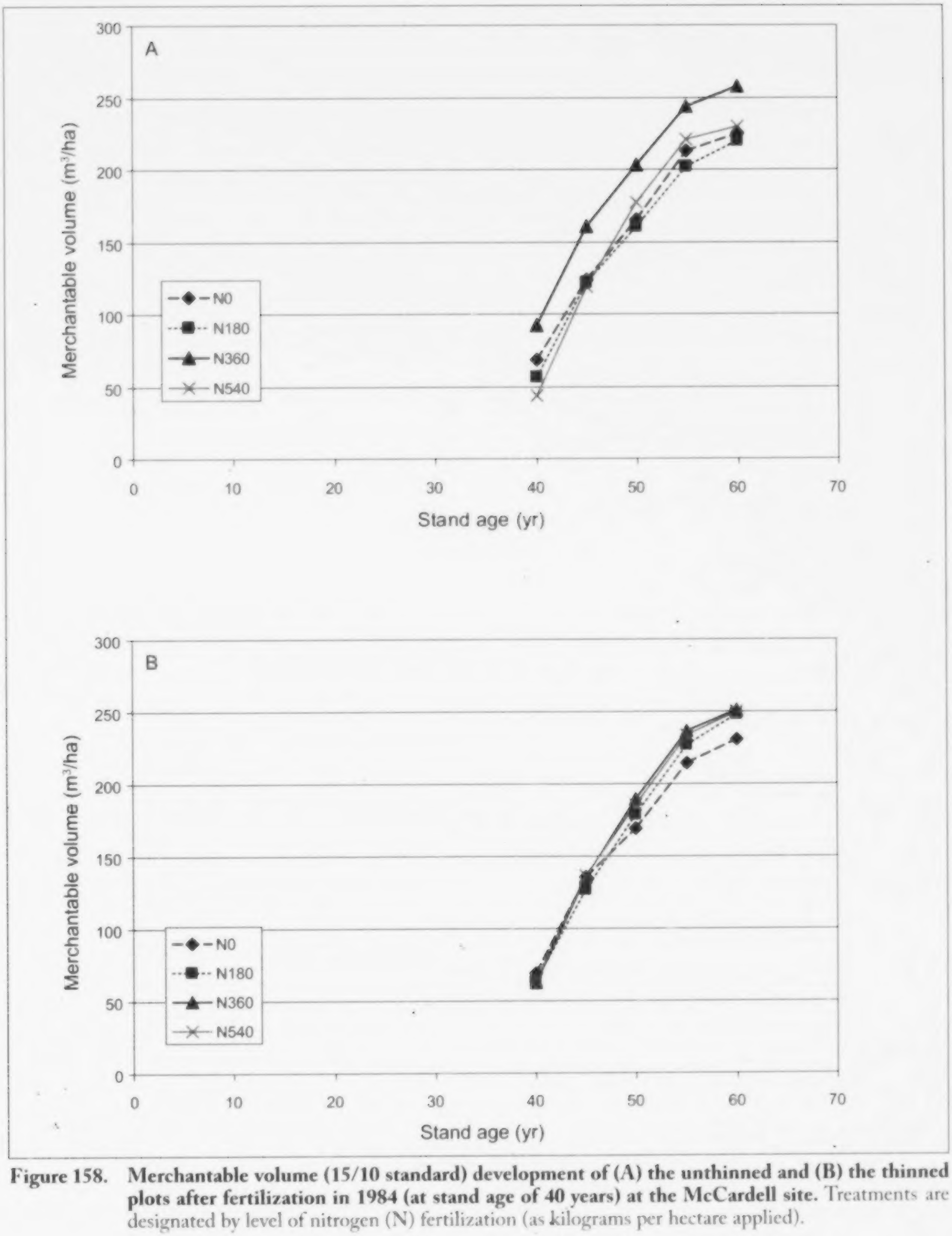

Figure 158. Merchantable volume (15/10 standard) development of (A) the unthinned and (B) the thinned plots after fertilization in 1984 (at stand age of 40 years) at the McCardell site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

Takyi Fertilization and Thinning Experiment (1980), PSP 7008—Medium Productivity Site

Location and Access

The Takyi medium productivity experiment site (53°19.1'N, 116°19.6'W, legal location 18-50-16-W5) is located about 30 km south of Edson. To access the Takyi medium productivity site from Edson, follow these directions:

Travel 3.5 km west from Edson on Highway 16 to Range Road 181A (Schlick Road).

Turn left (south) on Range Road 181A (Schlick Road) and travel 36.1 km.

Look for blue boundary paint and signs on the left.

Establishment and Objectives

The Takyi medium productivity fertilization and thinning experiment was established in 1980 by S. Takyi of the Alberta Lands and Forest Service in a medium productivity, densely stocked, 24-year-old, fire-origin lodgepole pine stand. The objectives of the experiment were to examine the effects of thinning and/or fertilizers on overstocked lodgepole pine, to provide information for development of pine growth and yield relationships for modeling purposes, and to estimate the operational response of pine to thinning and fertilizing. There have been no previous publications from this experiment.

Site Description

The Takyi medium productivity site is in the Lower Foothills ecological subregion of west-central Alberta, situated on a shallow midslope position (4-6% grade) on morainal parent material. Soils are Bisequa Grey Luvisols. The moisture regime is classed as mesic and the ecological nutrient regime as medium. This site was classified as having E1.3 lodgepole pine/feather moss and D1.3 lodgepole pine-black spruce/feather moss plant communities.

Experimental Design and Treatments

The Takyi medium productivity experiment has a randomized split-plot complete-block design with factorial arrangement of fertilization and thinning treatments in the whole plots and N source applied in the split-plots. Split-plots are 32 m × 16 m, with 16.67 × 6 m measurement plots nested within them. The two thinning treatments were a uniform, selective, single-tree thinning carried out by hand to a final density of 1600 stems per hectare and a simulated mechanical thinning carried out in strips, removing 75% of the trees; there was also an unthinned control. Because of problems with the data, the strip thinning treatment has been dropped from active study. There were four fertilization treatments (no fertilizer, 150 kg/ha P + 200 kg/ha K, 200 kg/ha N + 150 kg/ha P + 200 kg/ha K, and 400 kg/ha N + 150 kg/ha P + 200 kg/ha K). The two treatments with nitrogen were doubled, half using urea as the N source and half using ammonium nitrate. Four replicate blocks containing all 18 treatment combinations were established.

Originally, 12 sample trees within each treatment plot were tagged, and height and diameter at breast height were measured in 1979, 1982, and 1990. In 1999, measurement plots with fixed area were established, and all live trees in the plots were tagged. Diameter was measured for all trees with a diameter greater than 5 cm, and height, height to live crown, and crown radius were measured for approximately every third tree. Measurements in 1999 also included any original sample tree that happened to fall outside the measurement plot.

Results after 19 years

Tree Growth

Diameter development in crop trees tended to be relatively similar across fertilization treatments, but showed some differences with thinning treatments (Fig. 159). Trees in the thinned plots had considerably faster diameter growth than those in the unthinned plots, with increases of 8–9 cm and about 5 cm, respectively. Height growth seemed unaffected by fertilization and was increased only slightly (by about 0.6 m in the N400 treatments) by thinning (Fig. 160).

Stand Development

Fertilization had little effect on stem densities in the hand-thinned plots, where all densities were approximately equal (Fig. 161). The densities in the unthinned plots were much higher (as expected), and densities were lowest in the highest N treatment plots.

Although there was little difference in diameter distribution between fertilization treatments, there was a difference between the thinning treatments (Fig. 162). Diameters in the hand-thinned plots were larger (modal values 14–16 cm, compared with 6–10 cm) and more uniform than in the unthinned plots, which were also strongly skewed toward smaller diameters. Height–diameter relationships seemed unaffected by fertilization; however, trees in unthinned plots were significantly taller for a given diameter than those in thinned plots (Fig. 163).

Basal area in the thinned plots increased with increased N and was greater with urea as the N source than with ammonium nitrate (Fig. 164). This trend was less obvious in the unthinned plots, where N source had no consistent effect. The unthinned plots had greater basal area for all fertilization treatments.

The effects of fertilizer treatments on total and merchantable volumes were similar to those for basal area (Figs. 165, 166, and 167). Higher levels of N resulted in more volume, but N source made a difference only at the 200 kg/ha level. Total volumes were higher, but merchantable volumes lower, in the unthinned plots, since most of the trees in these plots were too small to have developed much merchantable volume; in contrast, the larger trees in the thinned plots had reached merchantable standards.

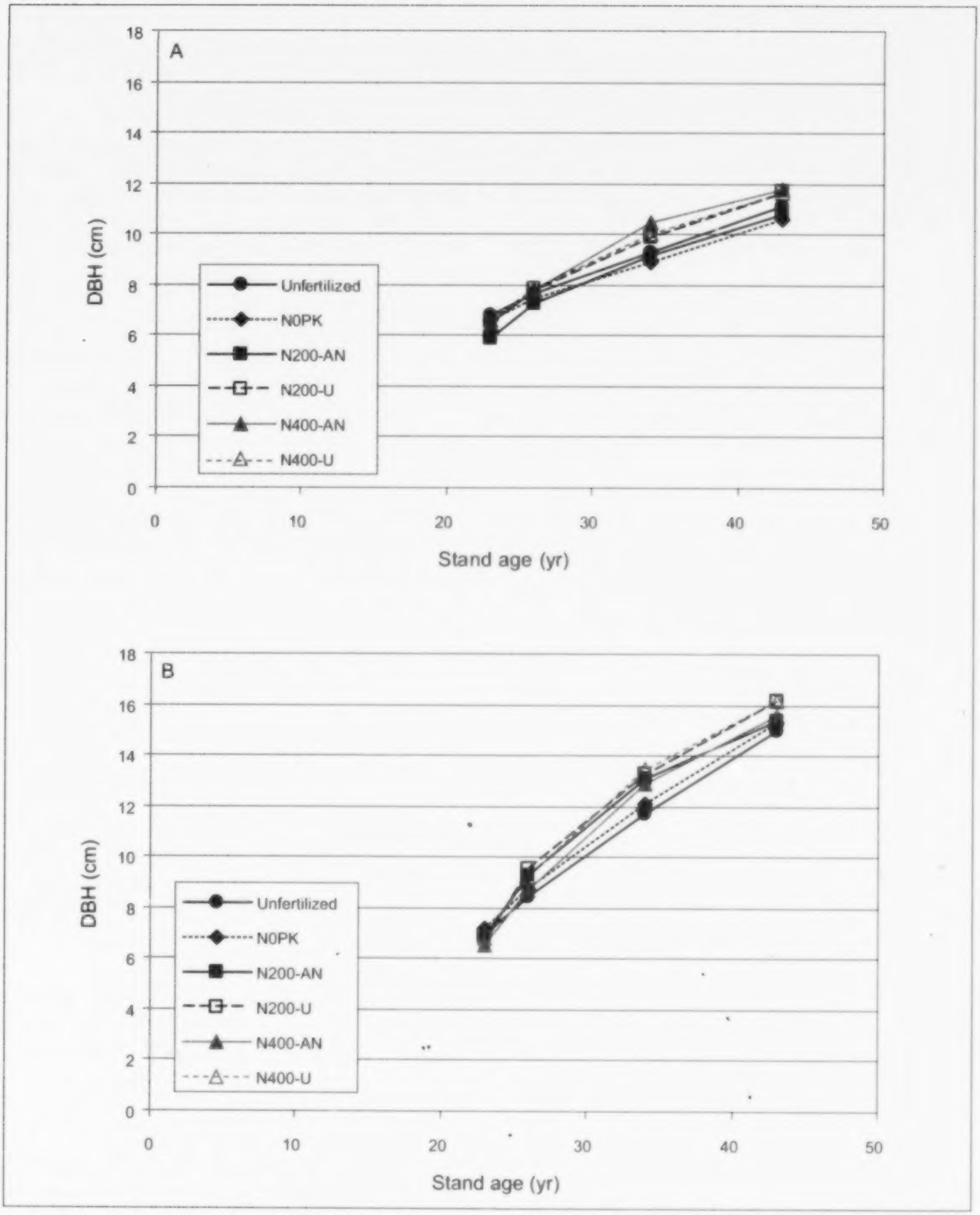

Figure 159. Diameter growth of (A) the unthinned and (B) the thinned plots after fertilization in 1980 (at stand age of 24 years) at the Takyi 7008 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). DBH = diameter at breast height, P = phosphorus, K = potassium.

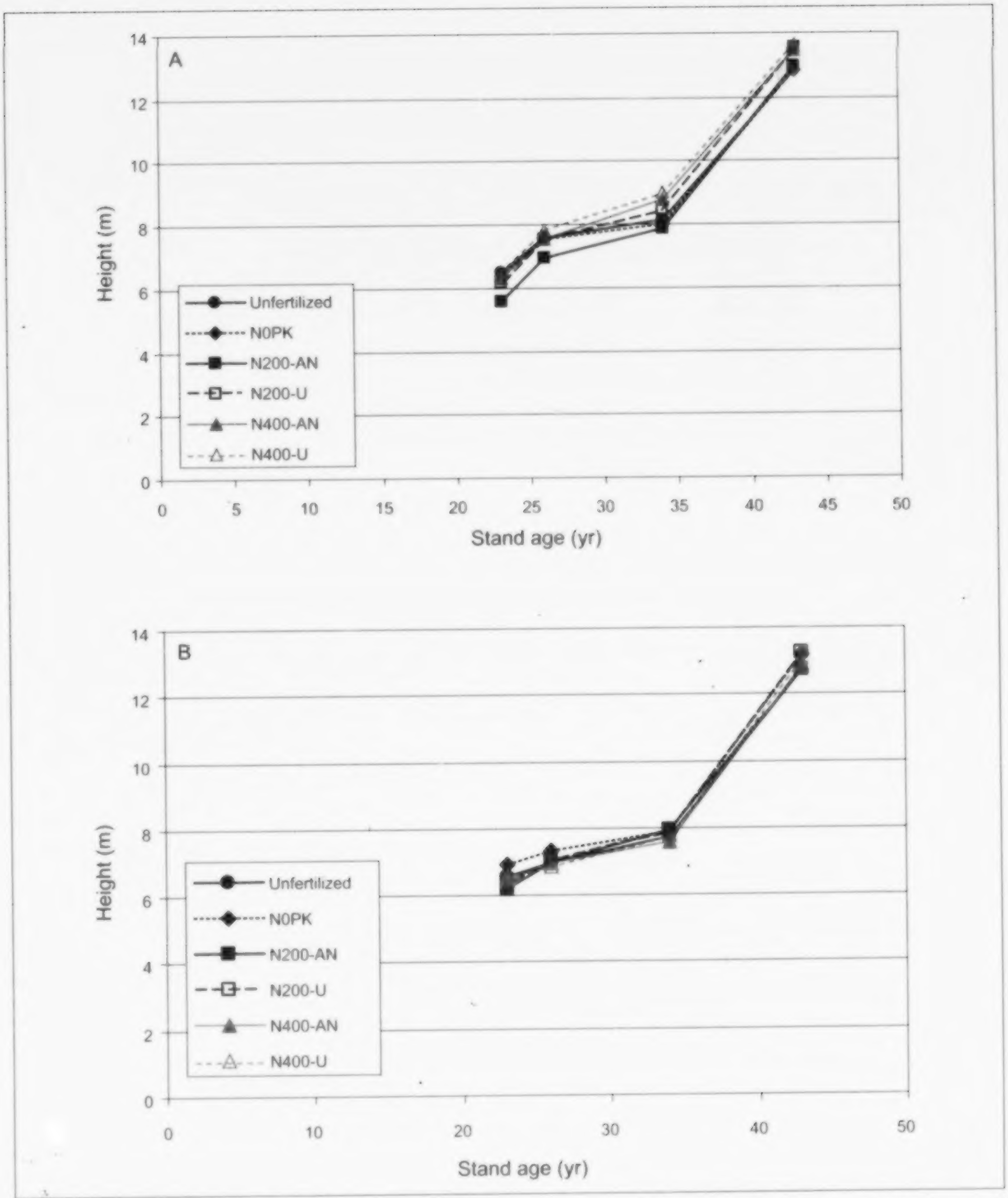

Figure 160. Height growth of (A) the unthinned and (B) the thinned plots after fertilization in 1980 (at stand age of 24 years) at the Takyi 7008 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). P = phosphorus, K = potassium.

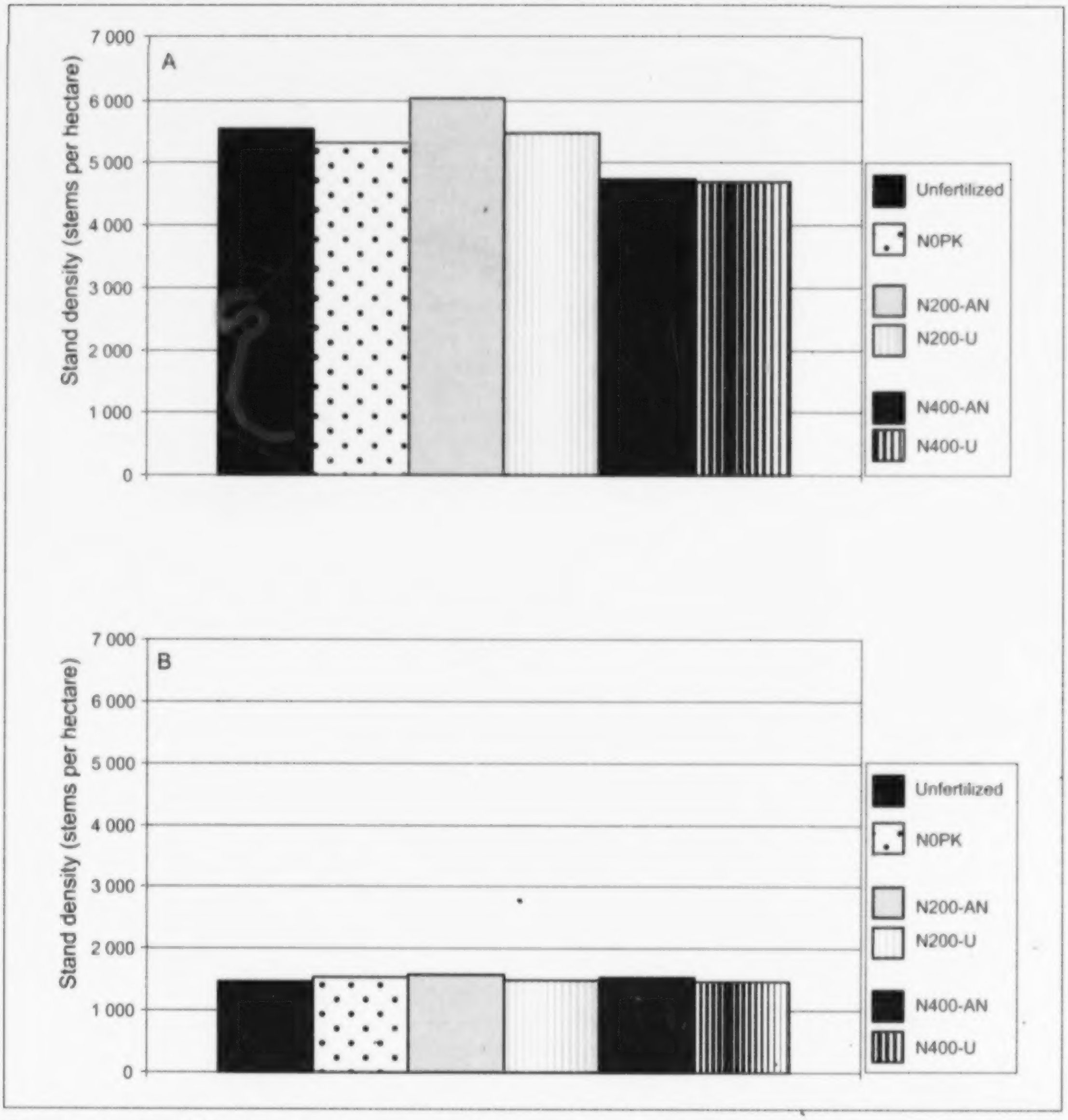

Figure 161. **Stand density at stand age 43 years of (A) the unthinned and (B) the thinned plots after fertilization in 1980 (at stand age of 24 years) at the Takyi 7008 site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). P = phosphorus, K = potassium.

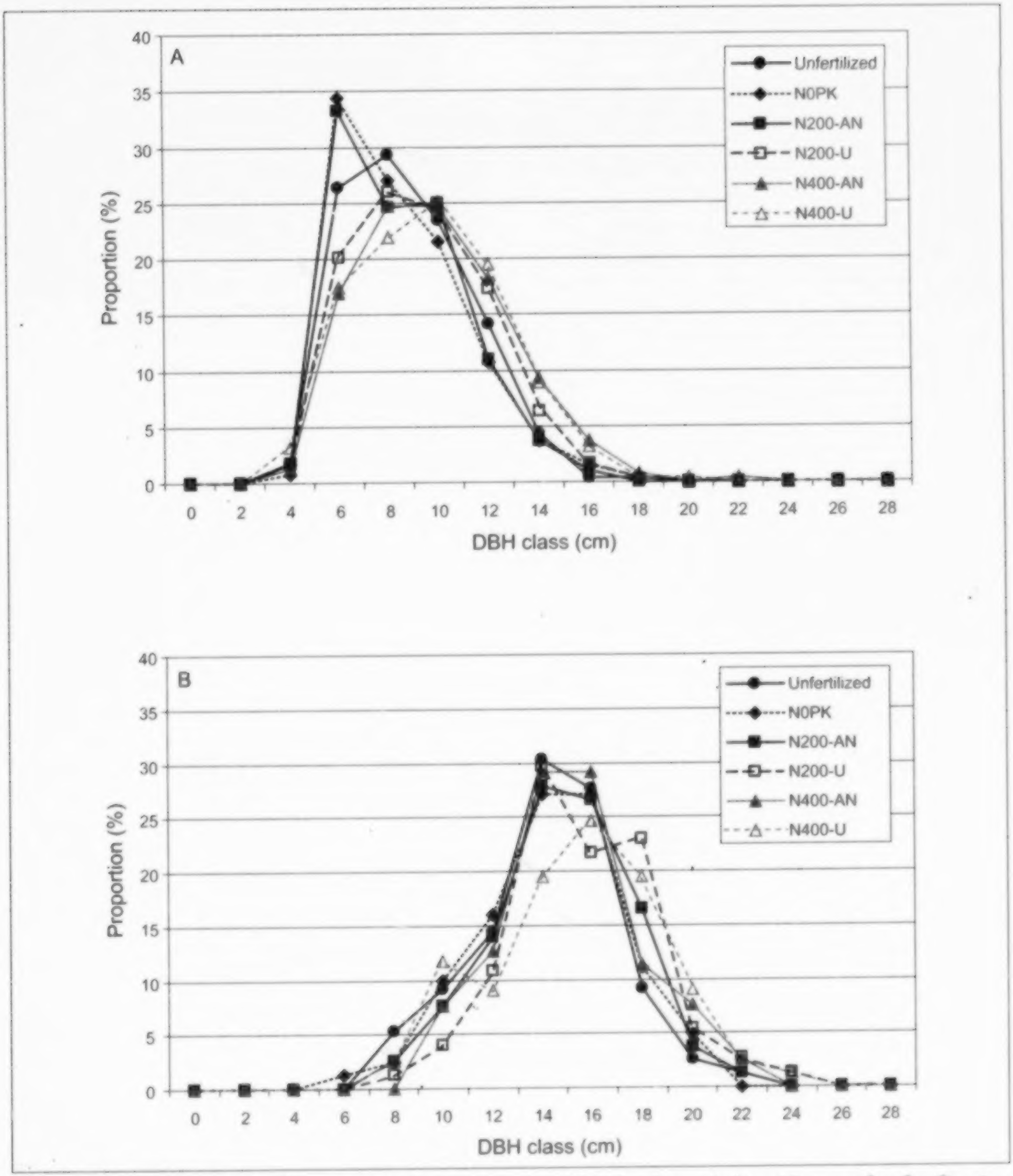

Figure 162. Diameter distribution of (A) the unthinned and (B) the thinned plots, 19 years after fertilization in 1980 at the Takyi 7008 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). DBH = diameter at breast height, P = phosphorus, K = potassium.

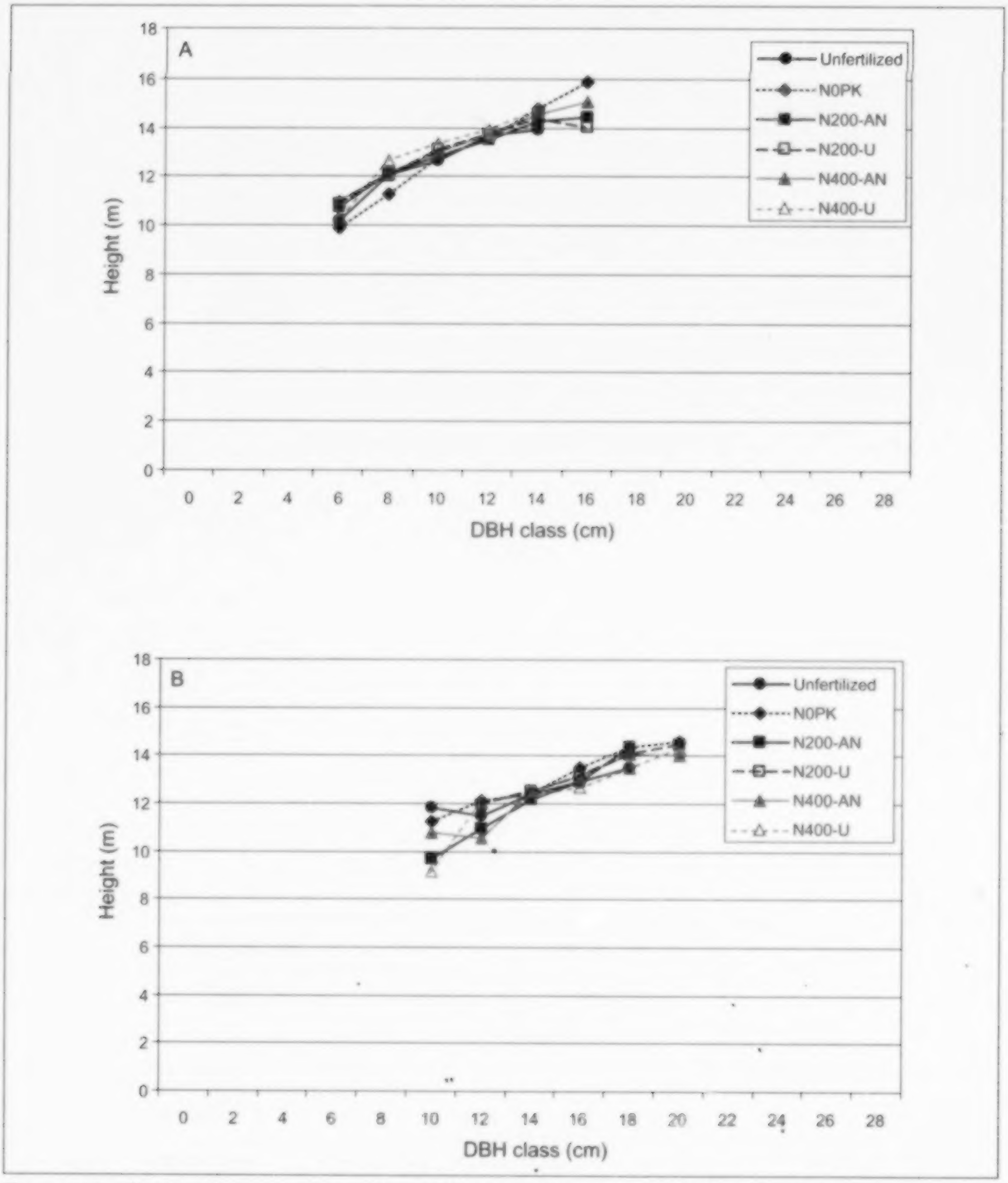

Figure 163. Height–diameter relationships of (A) the unthinned and (B) the thinned plots, 19 years after fertilization in 1980 at the Takyi 7008 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). DBH = diameter at breast height, P = phosphorus, K = potassium.

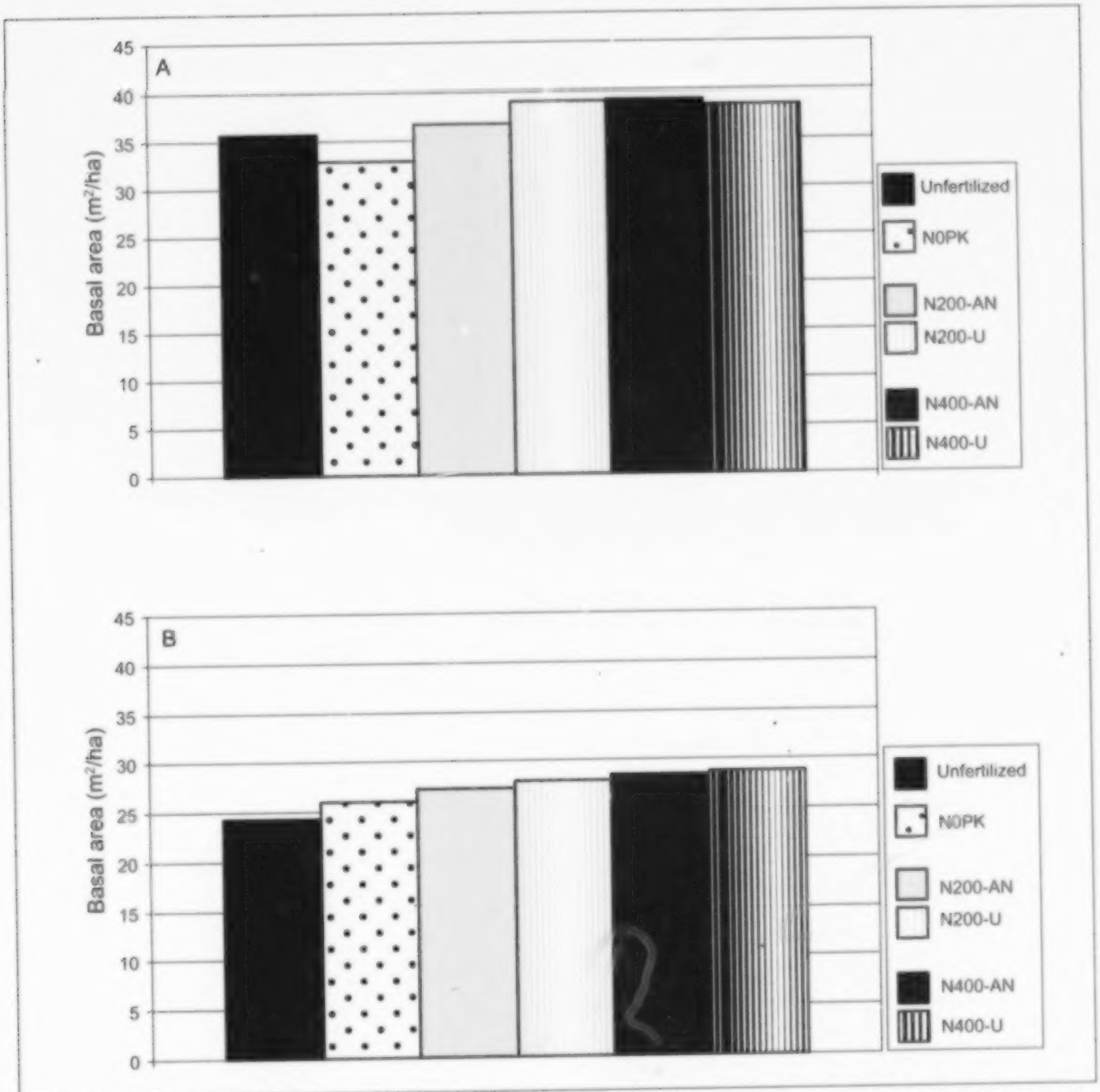

Figure 164. Basal area of (A) the unthinned and (B) the thinned plots, 19 years after fertilization in 1980 (at stand age of 24 years) at the Takyi 7008 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). P = phosphorus, K = potassium.

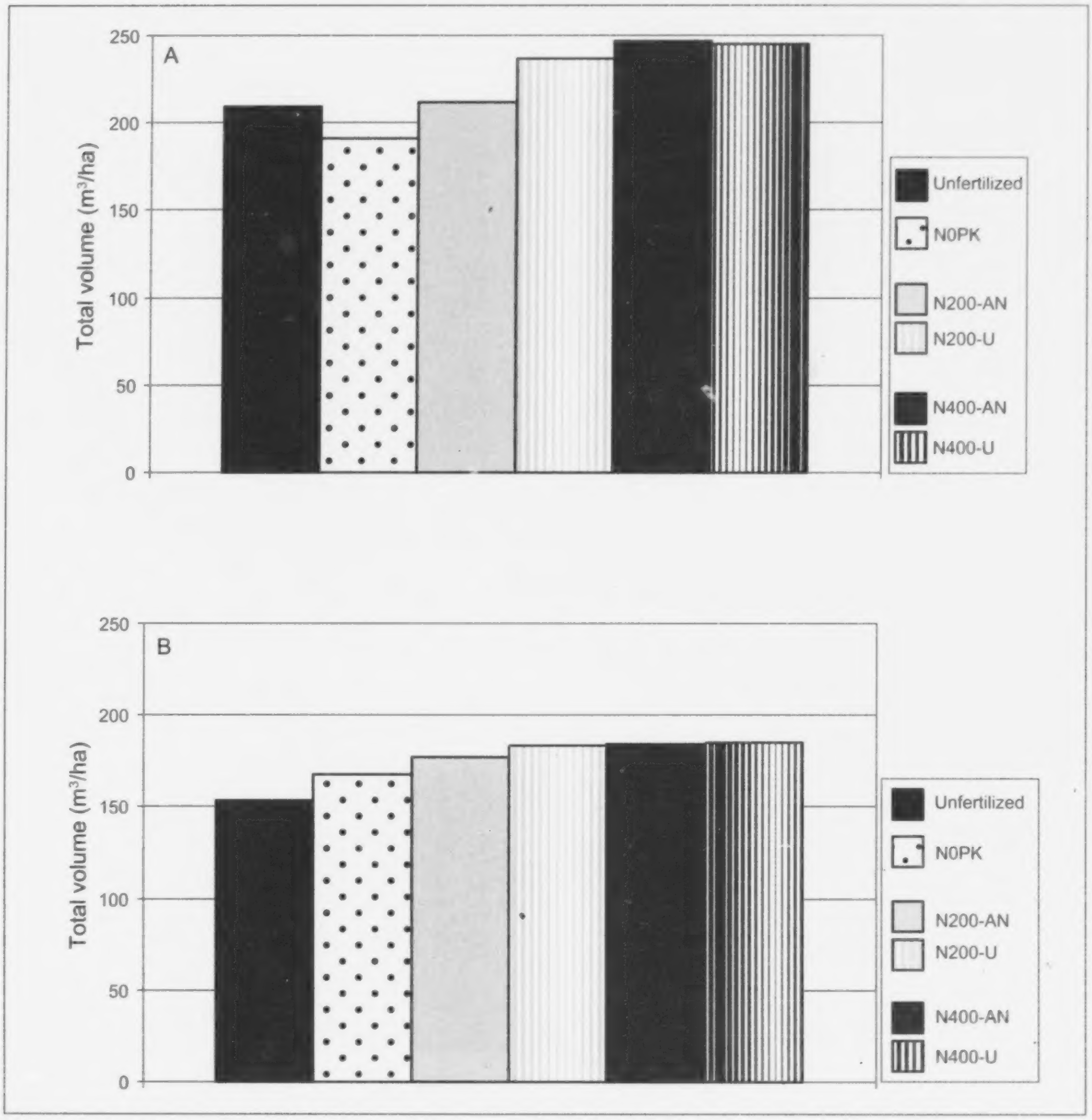

Figure 165. Total volume of (A) the unthinned and (B) the thinned plots, 19 years after fertilization in 1980 (at stand age of 24 years) at the Takyi 7008 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). P = phosphorus, K = potassium.

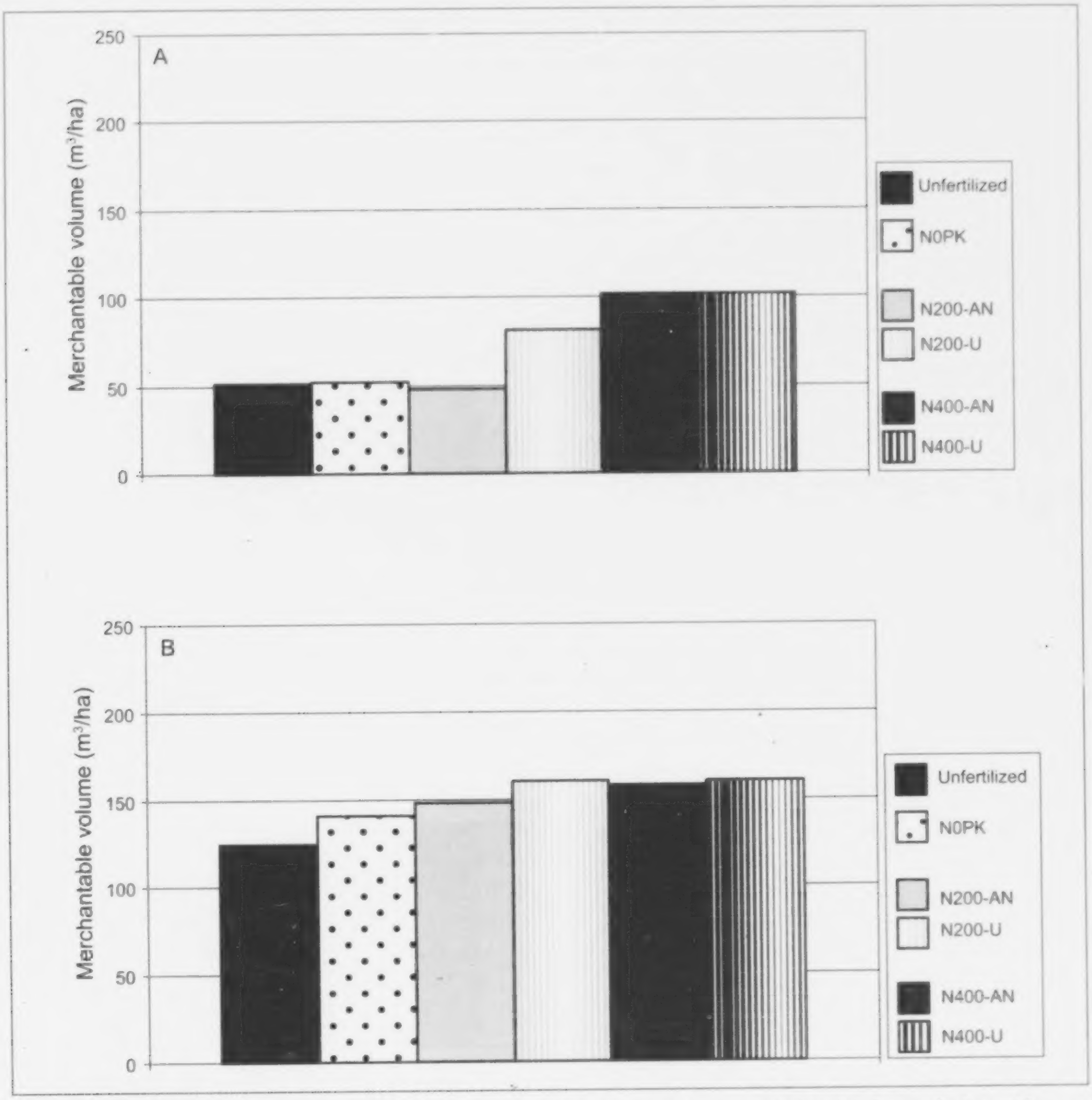

Figure 166. Merchantable volume (13/7 standard) of (A) the unthinned and (B) the thinned plots, 19 years after fertilization in 1980 (at stand age of 24 years) at the Takyi 7008 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). P = phosphorus, K = potassium.

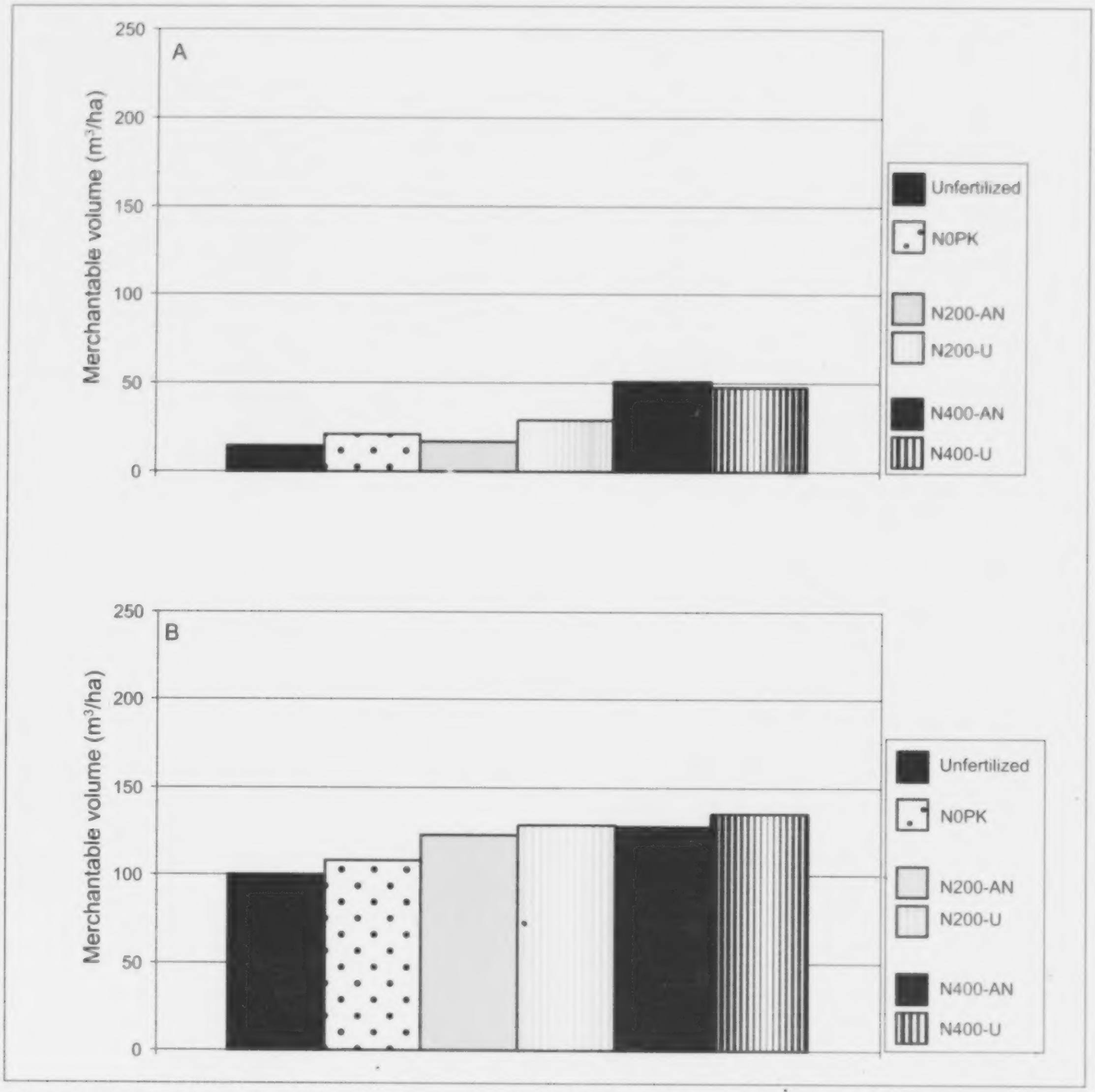

Figure 167. **Merchantable volume (15/10 standard) of (A) the unthinned and (B) the thinned plots, 19 years after fertilization in 1980 (at stand age of 24 years) at the Takyi 7008 site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied), either as ammonium nitrate (AN) or urea (U). P = phosphorus, K = potassium.

Takyi Fertilization and Thinning Experiment (1980), PSP 7009—Low Productivity Site

Location and Access

The Takyi low productivity experiment site (53°21.6'N, 116°25.4'W, legal location 33-50-17-W5) is located about 25 km south of Edson. To access the Takyi 7009 site from Edson, follow these directions:

Travel 3.5 km west from Edson on Highway 16 to Range Road 181A (Schlick Road).

Turn left (south) on Range Road 181A (Schlick Road) and travel 29 km.

Look for blue boundary paint and signs on the left.

Establishment and Objectives

The Takyi low productivity fertilization and thinning experiment was established in 1980 by S. Takyi of the Alberta Lands and Forest Service in a low productivity, densely stocked, 24-year-old, fire-origin lodgepole pine stand. The objectives of the experiment were to examine the effects of thinning and/or fertilization on overstocked lodgepole pine, to provide information for development of pine growth and yield relationships for modeling purposes, and to estimate the operational response of pine to thinning and fertilizing. There have been no previous publications from this experiment.

Site Description

The Takyi low productivity site is in the Lower Foothills ecological subregion of west-central Alberta, situated on level terrain. Soils are Orthic Grey Luvisols. The moisture regime is mesic, and the ecological nutrient regime is poor. This site was classified as having a D1.2 lodgepole pine-black spruce/green alder/feather moss plant community.

Experimental Design and Treatments

The Takyi low productivity experiment has a randomized split-plot complete-block design with factorial arrangement of fertilization and thinning treatments. Treatment plots are 32 m × 20 m, with 21 m × 9 m measurement plots nested within them. The two thinning treatments were a uniform, selective, single-tree thinning carried out by hand to a final density of 1600 trees per hectare and a simulated mechanical thinning carried out in strips, removing 75% of the trees; there was also an unthinned control. Because of problems with the data, the strip thinning treatment has been dropped from active study. There were three fertilization treatments (no fertilizer, 250 kg/ha N + 150 kg/ha P + 200 kg/ha K, and 500 kg/ha N + 300 kg/ha P + 400 kg/ha K). Four replicate blocks containing all 9 treatment combinations were established.

Originally, 12 sample trees within each treatment plot were tagged, and their diameter, height, height to live crown, and crown width were measured in 1979, 1982, and 1990. In 1999, the measurement plots with fixed area were established, and all live trees in the plots were tagged. Diameter was measured for all trees with diameter greater than 5 cm, and height, height to live crown, and crown radius were measured for approximately every third tree. Measurements in 1999 included any original sample tree that happened to fall outside the measurement plot.

Results after 19 Years

Tree Growth

Although trees in the hand-thinned plots increased in diameter at a faster rate than those in the unthinned plots, both showed a steady increase in diameter (Fig. 168). Diameter growth was greater for the N-fertilized treatments than the unfertilized treatments, but there was little difference (about 0.6 cm) between the two levels of fertilization.

Height growth among the different fertilization and thinning treatments was similar, and the greatest height difference in 1999 was only 1.2 m (between the control, at 10.8 m, and the N250 thinned treatment, at 12.0 m) (Fig. 169). There was consistent height growth between 1979 and

1990 of about 0.21 m/yr, and then an increase in height growth rate to about 0.55 m/yr between 1990 and 1999.

Stand Development

As expected, stand densities for the unthinned plots were much greater than for the thinned plots, even 19 years after treatment (Fig. 170). N fertilization reduced stand density in three of the four fertilized treatments.

Diameter distributions reflected stand density trends: thinning had a major effect on diameter, raising the average diameter and diameter range by several diameter classes, whereas fertilization had a more subtle effect (Fig. 171). In unthinned plots, fertilization increased the proportion of larger diameter trees, without significantly changing the range or median value. In contrast, in the thinned plots, only the 500 kg/ha N treatment was associated with increased diameters over the unfertilized treatment.

Height–diameter relationships seemed relatively unaffected by fertilization but were strongly affected by thinning (Fig. 172). Trees in the unthinned plots showed greater height for a given diameter than those in the thinned plots.

In 1999, basal areas were larger in the unthinned plots than in the thinned plots; for example, the high N treatment had over 4 m^2/ha more basal area in the unthinned plots than in the thinned plots (Fig. 173). The lower N fertilization rate produced the greatest basal areas; here, lower mortality offset lower diameter growth.

Height–diameter differences between thinned and unthinned plots influenced total volumes, which did not vary greatly between thinning treatments despite the differences in basal area (Fig. 174). Within thinning treatments, however, total volume followed the same pattern as for basal area, in that the lower N fertilization rate yielded the greatest volume.

Merchantable volumes differed greatly from total volumes (Figs. 175 and 176). The thinned plots had almost five times as much merchantable volume as the unthinned plots. Although the two N treatments did not differ greatly, both had greater volumes than the unfertilized treatments in the thinned and unthinned plots.

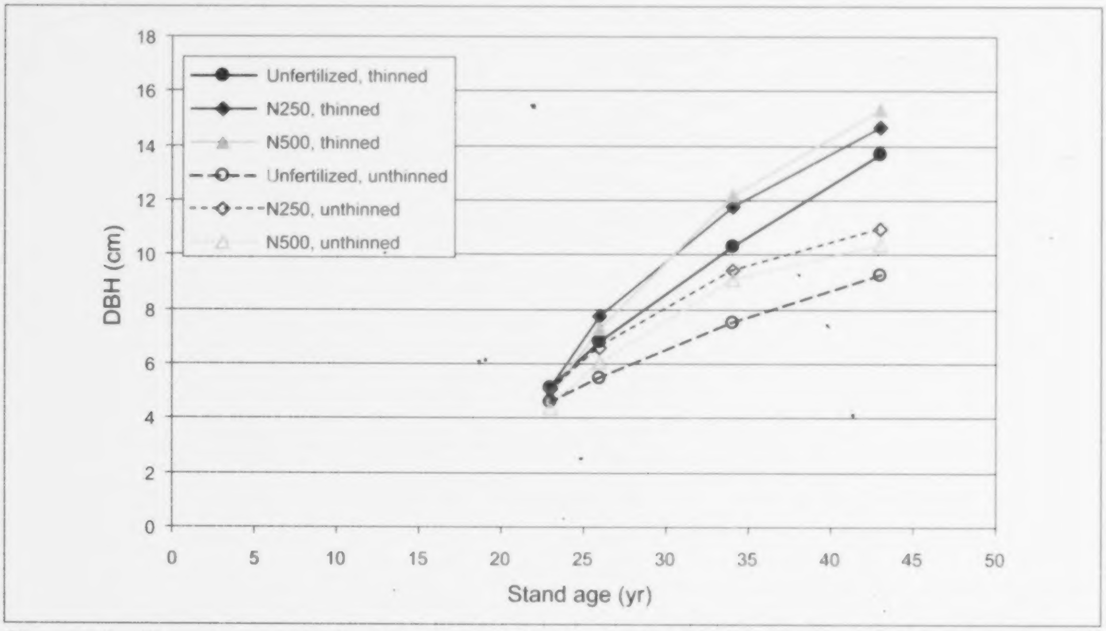

Figure 168. Diameter growth after thinning and fertilization in 1980 (at stand age of 24 years) at the Takyi 7009 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

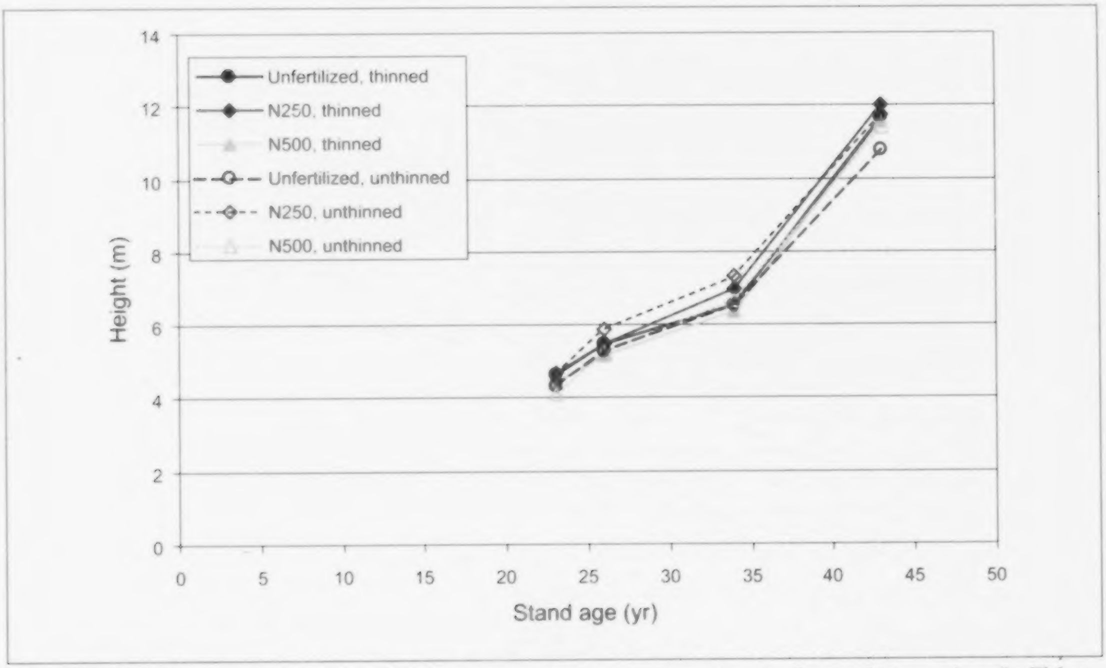

Figure 169. Height growth after thinning and fertilization in 1980 (at stand age of 24 years) at the Takyi 7009 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

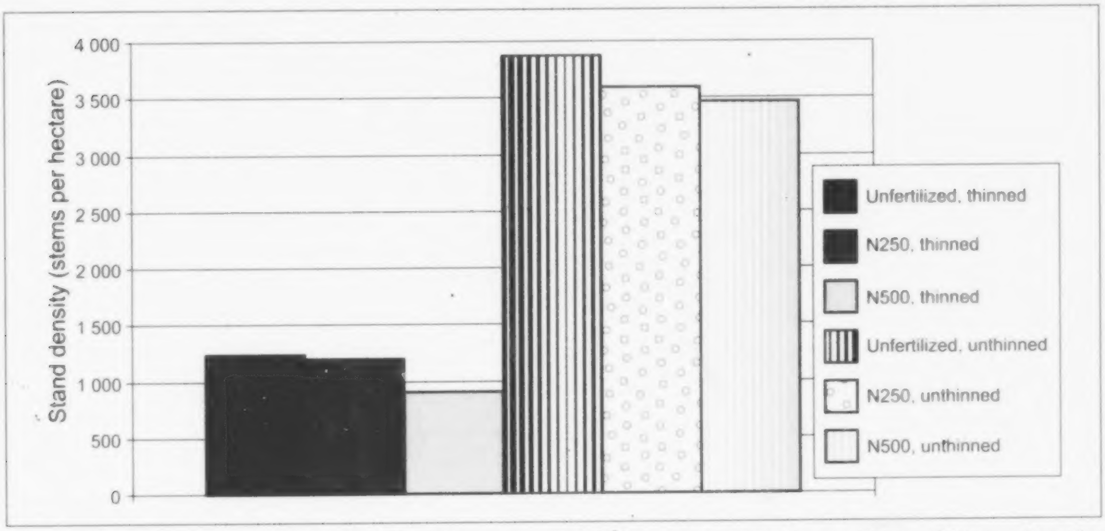

Figure 170. Stand density 19 years after thinning and fertilization in 1980 (at stand age of 24 years) at the Takyi 7009 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

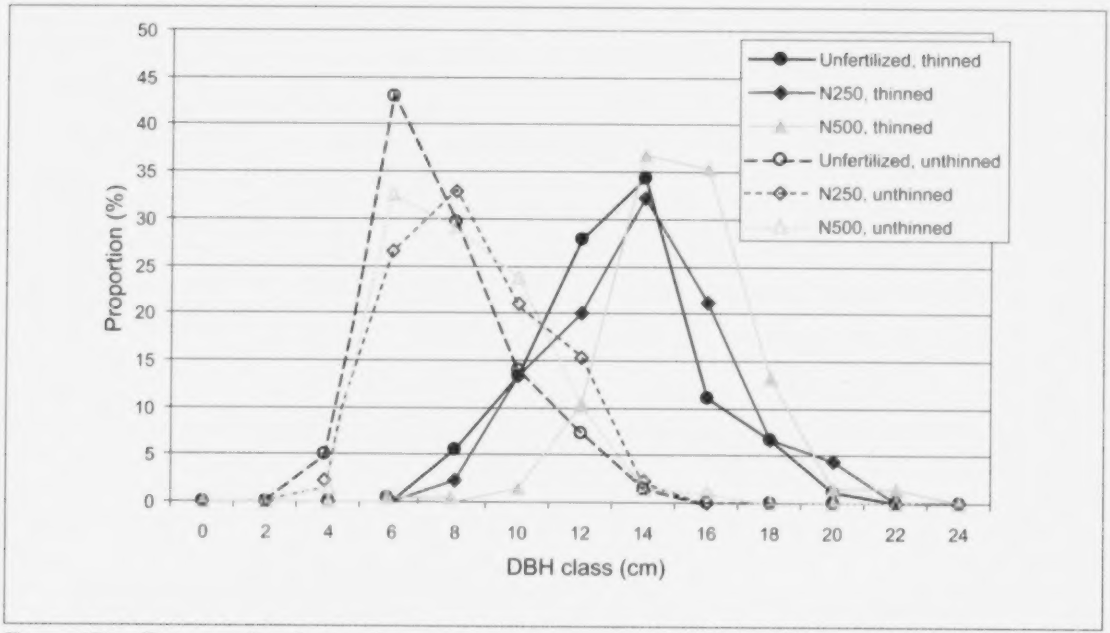

Figure 171. **Diameter distribution, by treatment, 19 years after thinning and fertilization in 1980 at the Takyi 7009 site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

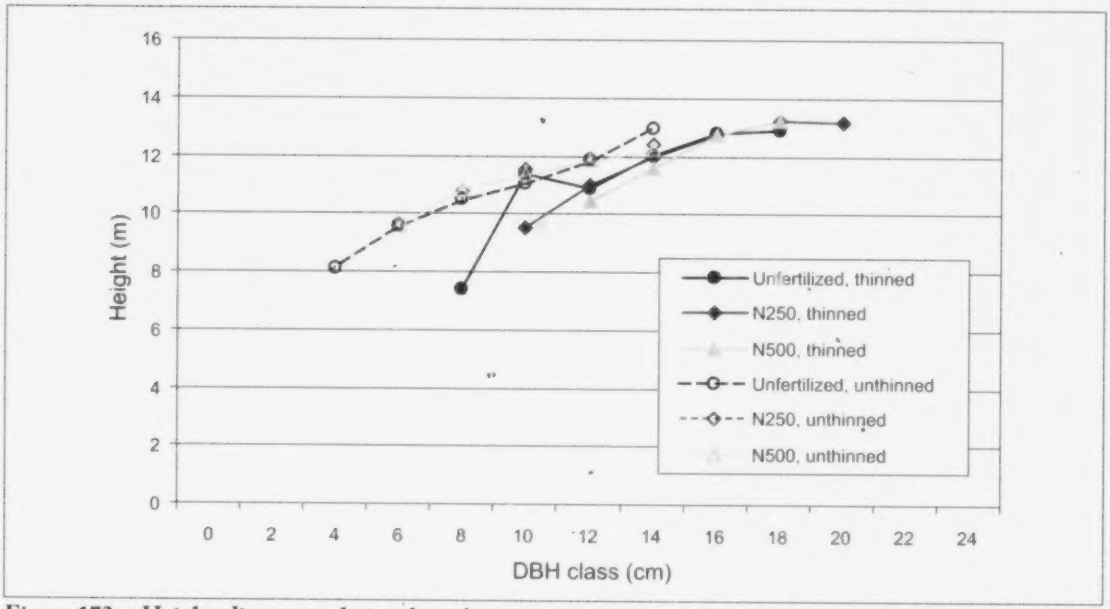

Figure 172. **Height–diameter relationships, by treatment, 19 years after thinning and fertilization in 1980 at the Takyi 7009 site.** Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied). DBH = diameter at breast height.

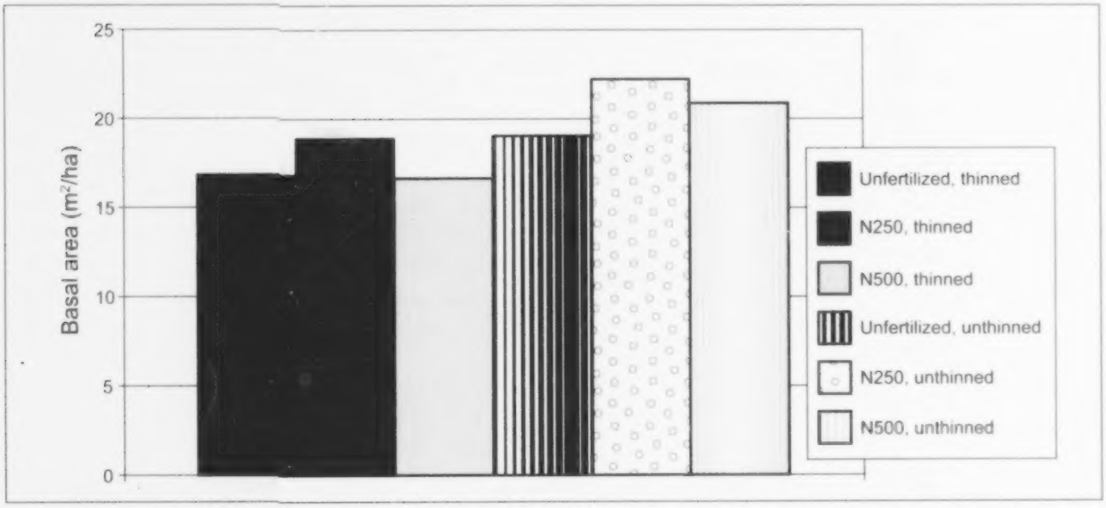

Figure 173. Basal area 19 years after thinning and fertilization in 1980 (at stand age of 24 years) at the Takyi 7009 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

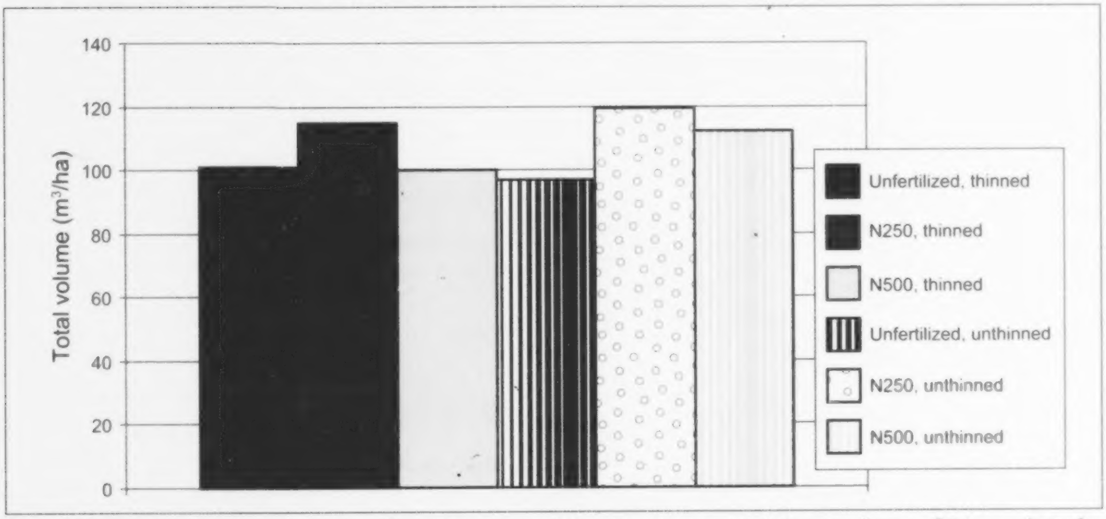

Figure 174. Total volume 19 years after thinning and fertilization in 1980 (at stand age of 24 years) at the Takyi 7009 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

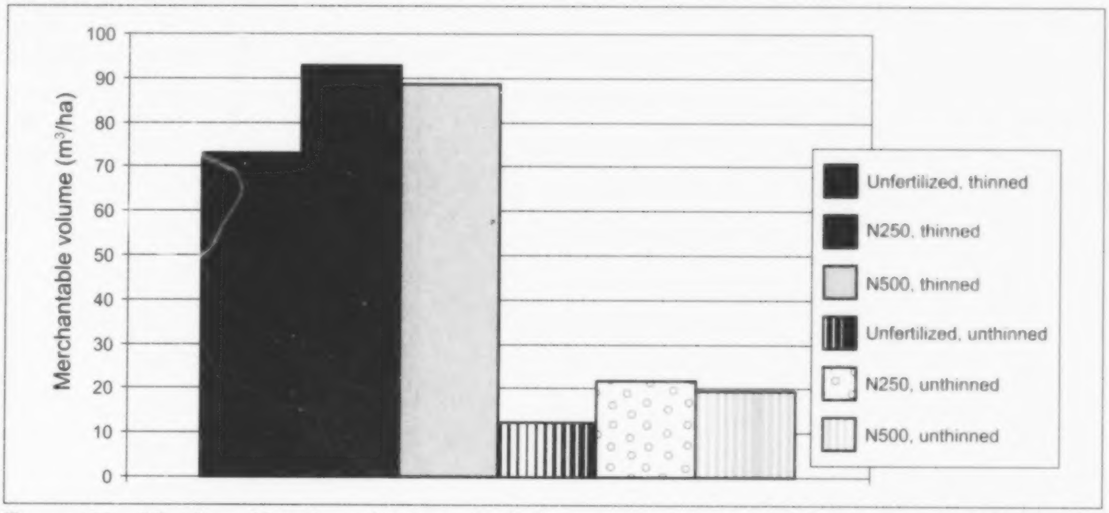

Figure 175. Merchantable volume (13/7 standard) 19 years after thinning and fertilization in 1980 (at stand age of 24 years) at the Takyi 7009 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

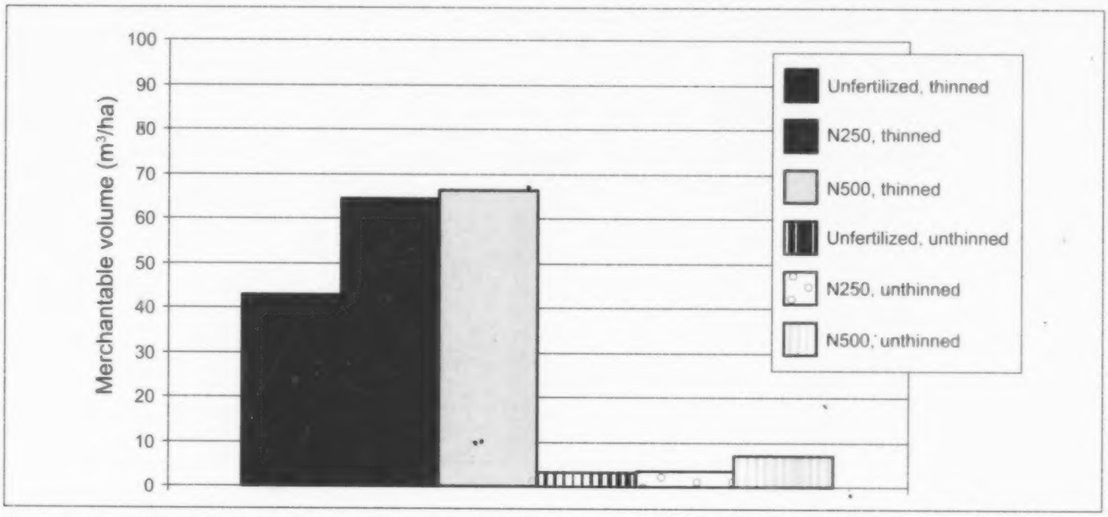

Figure 176. Merchantable volume (15/10 standard) 19 years after thinning and fertilization in 1980 (at stand age of 24 years) at the Takyi 7009 site. Treatments are designated by level of nitrogen (N) fertilization (as kilograms per hectare applied).

Conclusions

The 12 field experiments and trials described in this report span a broad range of ecological characteristics and silvicultural treatments. The field sites cover four ecosites in three natural subregions, nine different ecosite phases, and 12 different plant community types. Despite this range of conditions and the large amount of data that is accumulating in the database, there are limits to what can be learned from these studies because of the following constraints:

- There were only three installations where fertilization was combined with thinning treatments, and in those trials only one level of thinning was tested.
- Fertilization was performed only at mesic sites, not on drier or wetter sites.
- Trials were located on poor to medium sites, not on richer or very poor sites.
- Thinning was done mostly at mesic sites, with only a few thinning treatments at submesic and subhygric sites.
- Most of the studies involved treatments carried out before stand age of 30 years; few studies looked at the middle or later years of stand development.
- Commercial thinning was represented in only three studies, two of which suffered from pseudoreplication.

Although it is not the intent of this report to interpret or draw conclusions from these results, some noticeable trends have been revealed:

- Fertilization had more effect on growth and yield in unthinned than in thinned stands.
- Site quality had a major effect on diameter growth and hence on volume growth.
- Fertilization was often associated with increased mortality and appeared to inhibit the development of ingrowth.
- Fertilization was generally associated with increased diameter growth, but this effect was not always reflected in increased basal area or volume because of the increased mortality.
- Greater growth of individual trees at wider spacings usually did not make up for the reduction in number of stems, and therefore stand growth (basal area or volume) increased with increasing stand densities, although usually not up to the densities of unthinned plots.
- Trees responded to thinning at all of the ages tested.

The field installations continue to be managed and measured collaboratively by the Canadian Forest Service, Foothills Growth and Yield Association, and Alberta Sustainable Resource Development.

Acknowledgments

We wish to acknowledge the contributions of the late D. Presslee and of S. Lux in setting in motion the process that led to the production of this report. We also thank H. Lougheed, T. Braun, S. Navratil, B. Udell, and all of the participants of the three field tours of the historical pine trials for their interest in these plots and discussions about these results. We gratefully acknowledge the substantial financial and technical support provided by the Foothills Growth and Yield Association (FGYA) and Alberta Sustainable Resource Development (ASRD). We give special thanks to D. Dempster (FGYA), H. Lougheed (FGYA), and D. Morgan (ASRD) for their part in setting up the collaborative management protocol that maintains and makes use of these field studies. D. Gilday and D. Morgan provided the data and information on the Takyi plots. M. Voicu and A. Dawson assisted with data analysis and production of graphs. J. Martin-DeMoor produced the access maps and first drafts of the site layout maps. We thank D. Dempster, D. Morgan, and R. Yang for reviewing a previous draft of this report.

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Appendix 1

List of species

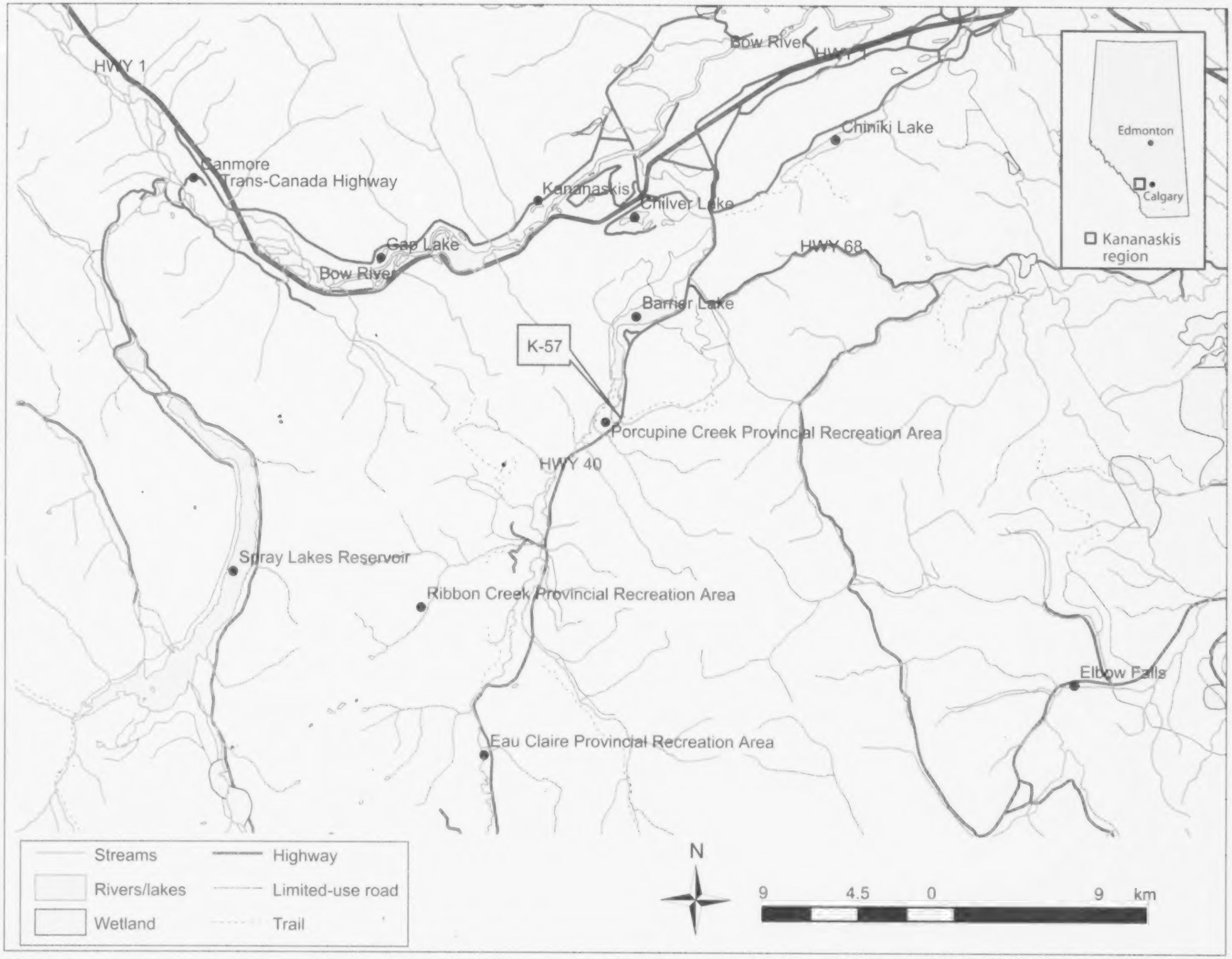
List of species[a]

Common name	Scientific name
Black spruce	*Picea mariana* (Mill.) BSP
Bog cranberry	*Vaccinium vitis-idaea* L.
Canada buffalo-berry	*Shepherdia canadensis* (L.) Nutt.
Feather moss	*Ptilium crista-castrensis* (Hedw.) De Not. *Hylocomium splendens* (Hedw.) B.S.G. *Pleurozium schreberi* (Brid.) Mitt.
Green alder	*Alnus crispa* (Ait.) Pursh
Hairy wild rye	*Elymus innovatus* Beal
Labrador tea	*Ledum groenlandicum* Oeder
Lodgepole pine	*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.
Trembling aspen	*Populus tremuloides* Michx.
White spruce	*Picea glauca* (Moench) Voss
Wild sarsaparilla	*Aralia nudicaulis* L.

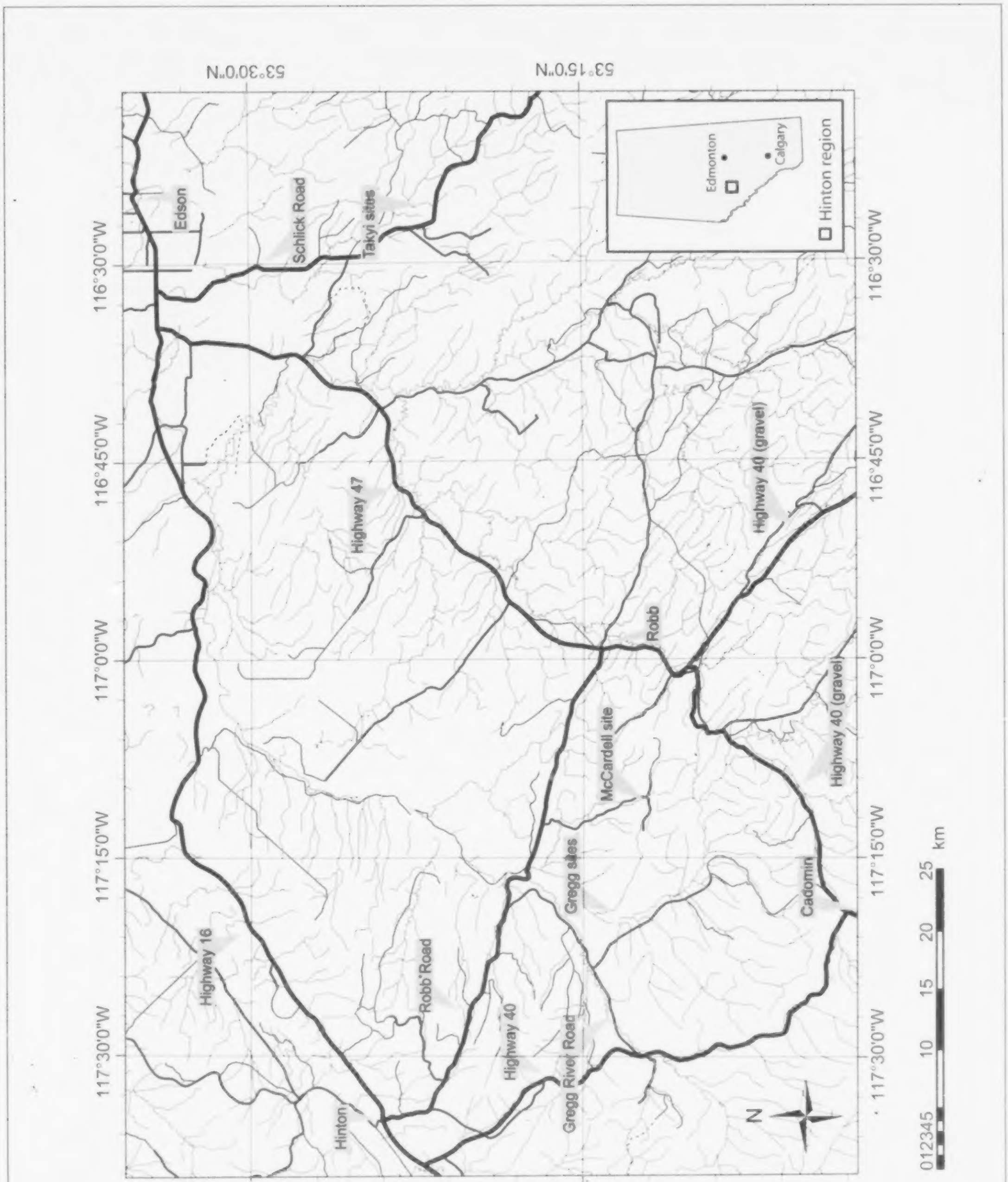
[a] Scientific names and authorities follow the field guides to ecosites in southwestern Alberta (Archibald, J.H.; Klappstein, G.D.; Corns, I.G.W. 1996. Field guide to ecosites of southwestern Alberta. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. Spec. Rep. 8) and west-central Alberta (Beckingham, J.D.; Corns, I.G.W; Archibald, J.H. 1996. Field guide to ecosites of west-central Alberta. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. Spec. Rep. 9).

Appendix 2

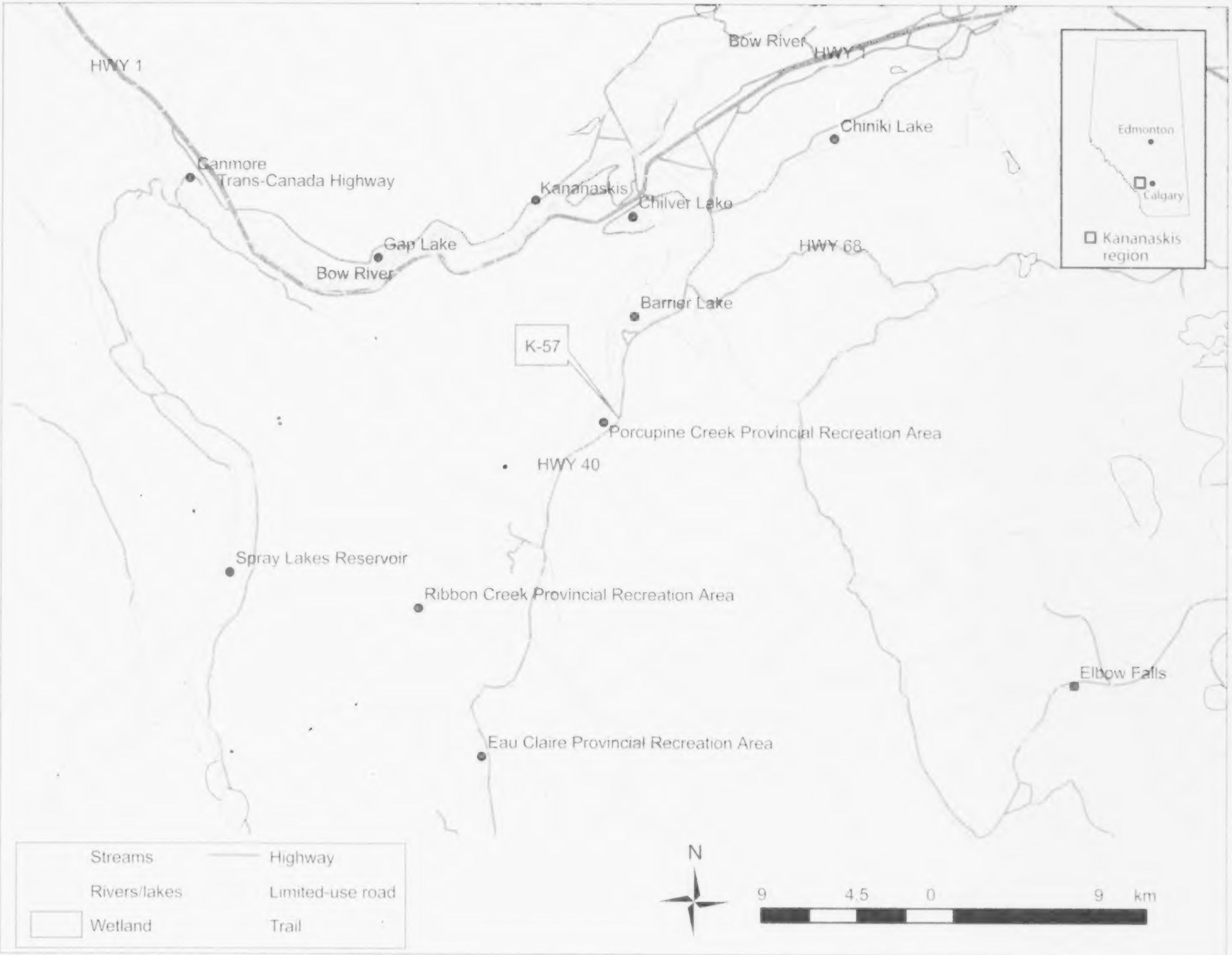
Study locations


HWY 1
Canmore
Trans-Canada Highway
Gap Lake
Bow River
Kananaskis
Chilver Lake
Bow River
HWY 1
Chiniki Lake
HWY 68
Barrier Lake
K-57
Porcupine Creek Provincial Recreation Area
HWY 40
Spray Lakes Reservoir
Ribbon Creek Provincial Recreation Area
Eau Claire Provincial Recreation Area
Elbow Falls
Edmonton
Calgary
Kananaskis region
Streams
Rivers/lakes
Wetland
Highway
Limited-use road
Trail
N
9
4.5
0
9
km

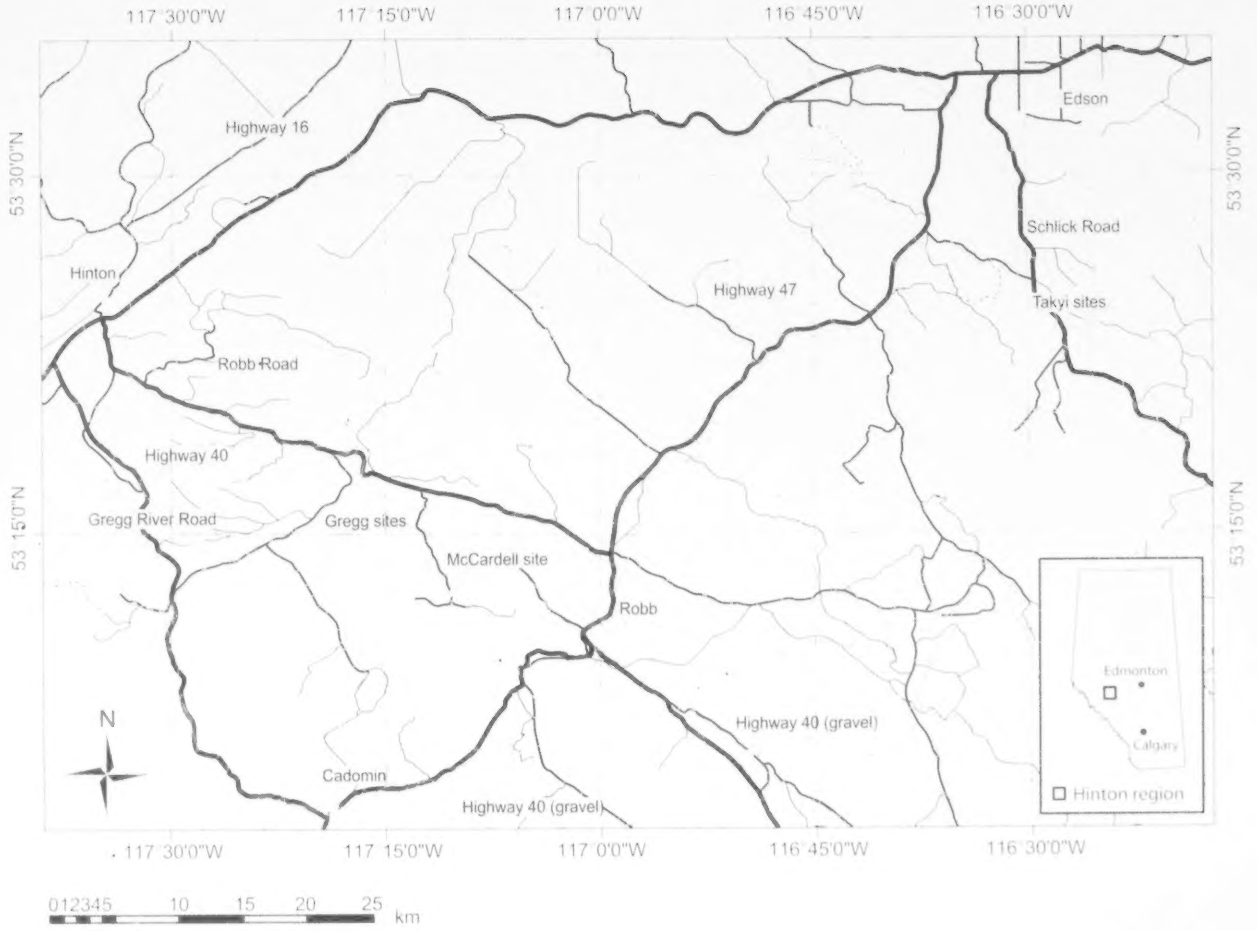
Historic pine trial access map—Kananaskis region.


53°30'0"N
53°15'0"N
116°30'0"W
116°45'0"W
117°0'0"W
117°15'0"W
117°30'0"W
Edson
Schlick Road
Takyi sites
Highway 47
Highway 16
Robb Road
Highway 40
Gregg River Road
Hinton
Gregg sites
McCardell site
Robb
Highway 40 (gravel)
Highway 40 (gravel)
Cadomin
Edmonton
Calgary
Hinton region
N
0 1 2 3 4 5 10 15 20 25 km

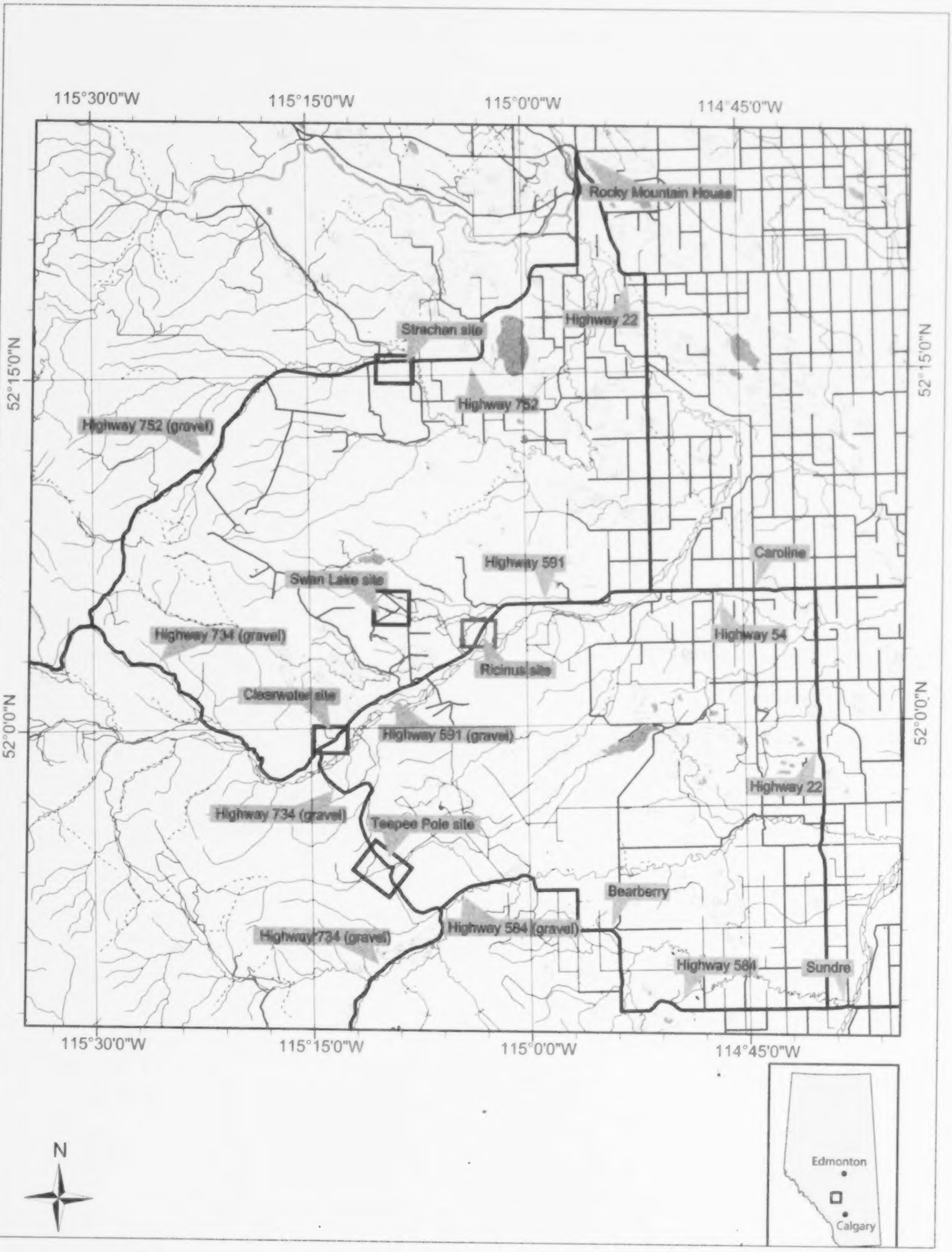
Historic pine trial access map—Hinton region.


HWY 1
Bow River
HWY 1
Chiniki Lake
Canmore
Trans-Canada Highway
Kananaskis
Chilver Lake
Gap Lake
Bow River
HWY 68
Barrier Lake
K-57
Porcupine Creek Provincial Recreation Area
HWY 40
Spray Lakes Reservoir
Ribbon Creek Provincial Recreation Area
Eau Claire Provincial Recreation Area
Elbow Falls
Edmonton
Calgary
Kananaskis region
Streams
Highway
Rivers/lakes
Limited-use road
Wetland
Trail
N
9
4.5
0
9
km

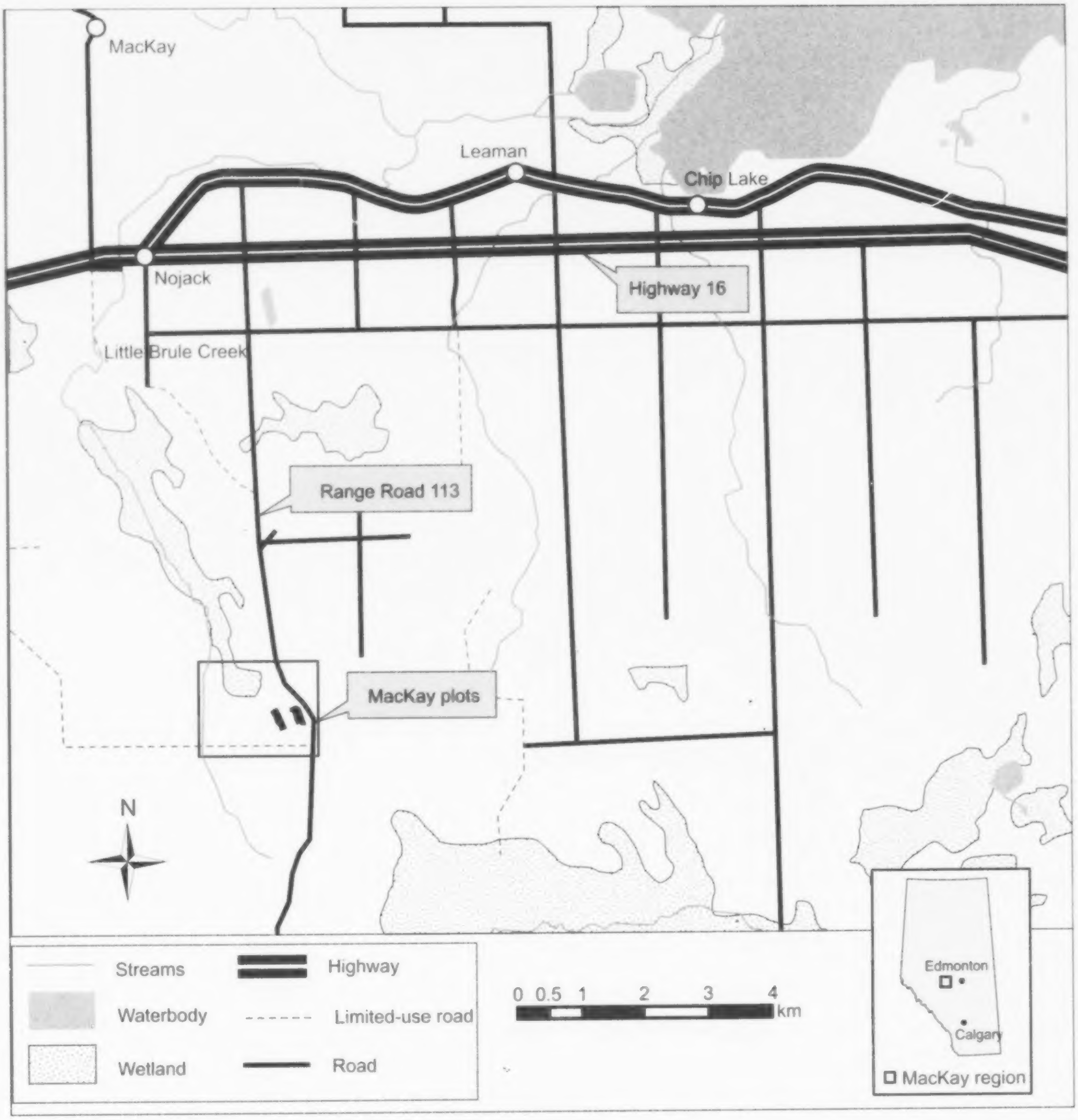
Historic pine trial access map—Kananaskis region.


117 30'0"W
117 15'0"W
117 0'0"W
116 45'0"W
116 30'0"W
53 30'0"N
53 15'0"N
Highway 16
Edson
Schlick Road
Hinton
Highway 47
Takyi sites
Robb Road
Highway 40
Gregg River Road
Gregg sites
McCardell site
Robb
Highway 40 (gravel)
Cadomin
Highway 40 (gravel)
N
Edmonton
Calgary
Hinton region
0 1 2 3 4 5 10 15 20 25 km

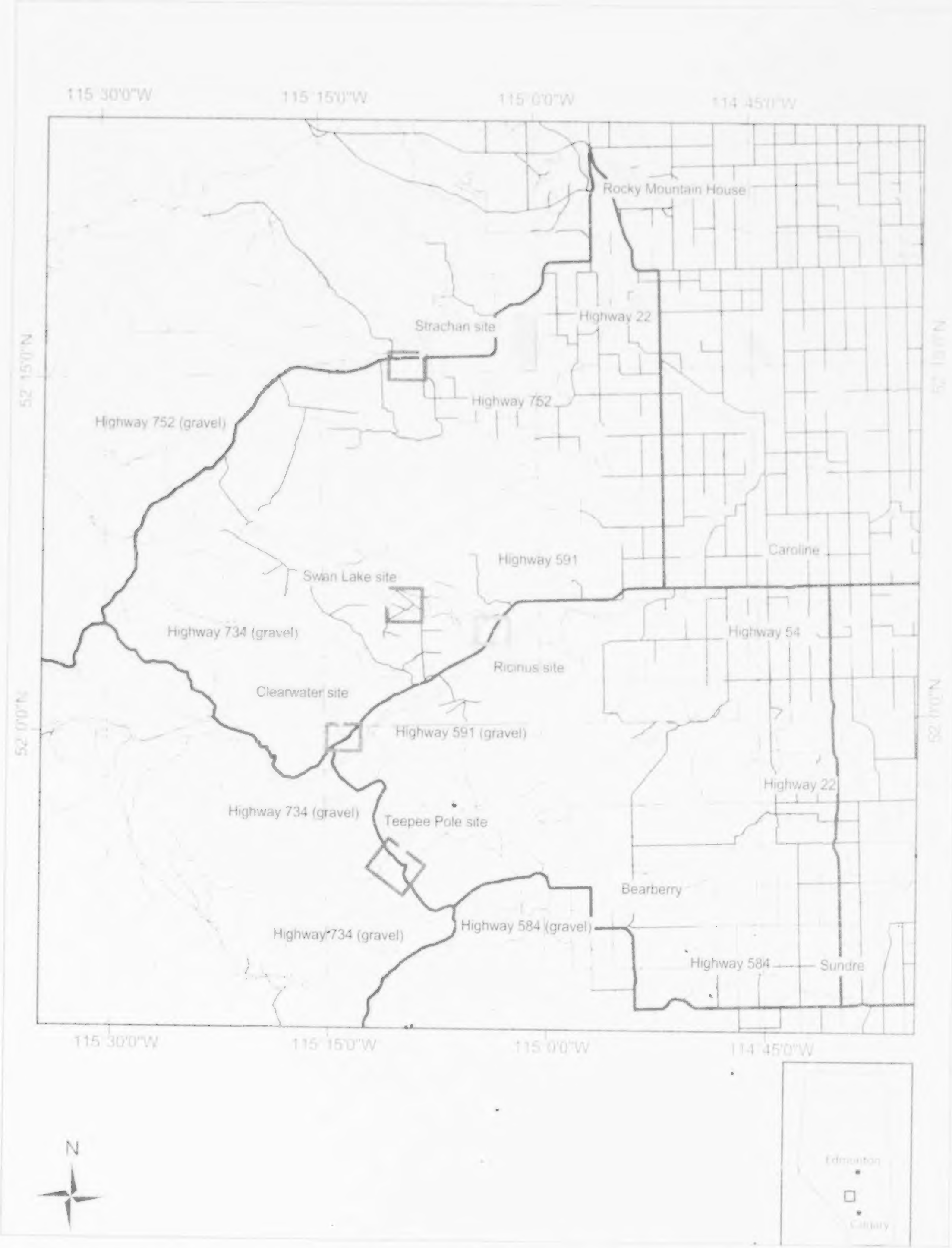
Historic pine trial access map—Hinton region.


115°30'0"W
115°15'0"W
115°0'0"W
114°45'0"W
Rocky Mountain House
Strachan site
Highway 22
52°15'0"N
Highway 752
Highway 752 (gravel)
Caroline
Highway 591
Swan Lake site
Highway 734 (gravel)
Highway 54
Ricinus site
Clearwater site
52°0'0"N
Highway 591 (gravel)
Highway 22
Highway 734 (gravel)
Teepee Pole site
Bearberry
Highway 584 (gravel)
Highway 734 (gravel)
Highway 584
Sundre
N
Edmonton
Calgary

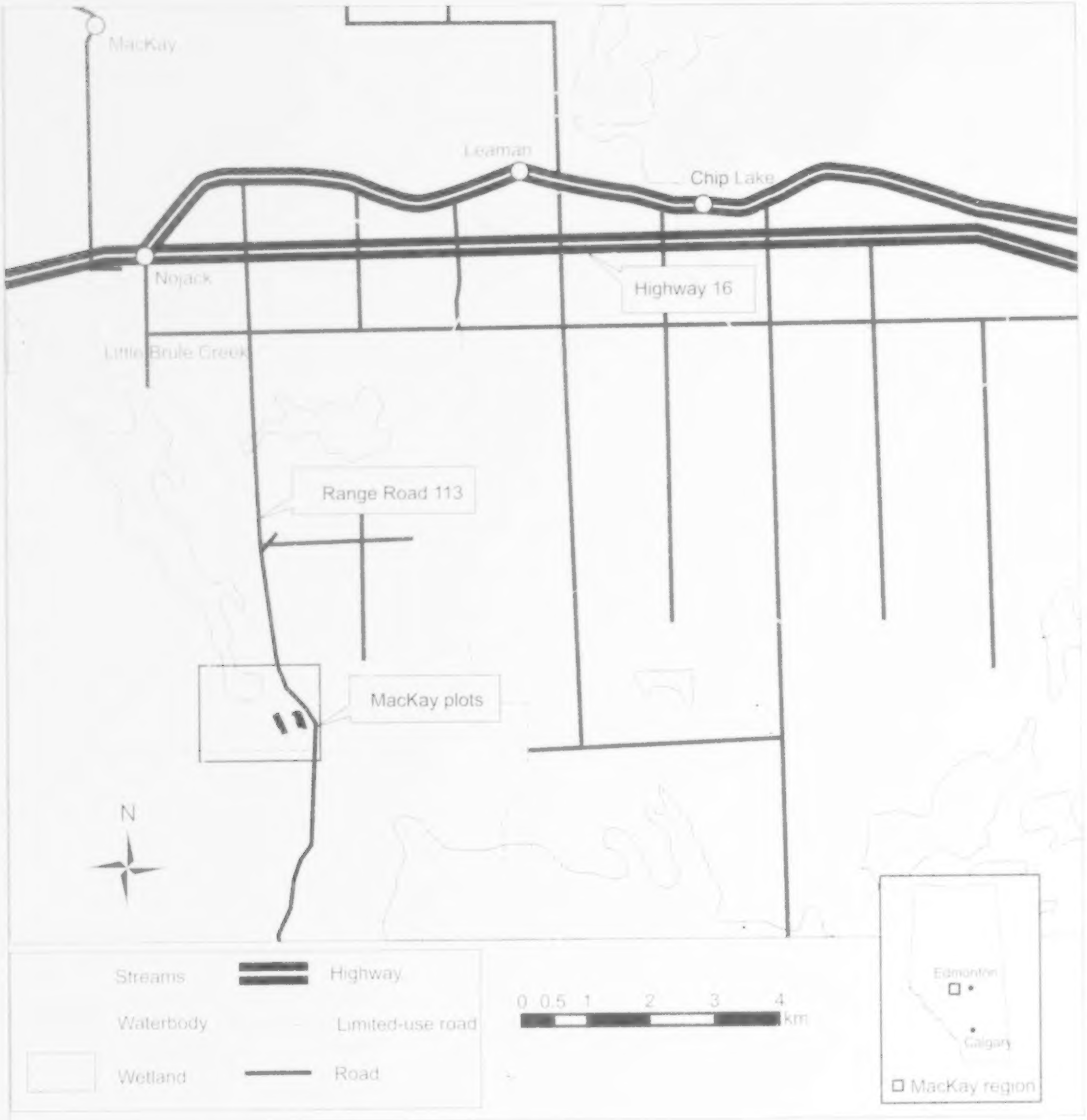
Historic pine trial access map—Rocky Mountain House region.


MacKay
Leaman
Chip Lake
Nojack
Highway 16
Little Brule Creek
Range Road 113
MacKay plots
N
Streams
Highway
Waterbody
Limited-use road
Wetland
Road
0 0.5 1 2 3 4 km
Edmonton
Calgary
MacKay region

Historic pine trial access map—MacKay region.


115°30'0"W
115°15'0"W
115°0'0"W
114°45'0"W
52°15'0"N
52°0'0"N
Rocky Mountain House
Strachan site
Highway 22
Highway 752
Highway 752 (gravel)
Highway 591
Swan Lake site
Caroline
Highway 734 (gravel)
Highway 54
Ricinus site
Clearwater site
Highway 591 (gravel)
Highway 22
Highway 734 (gravel)
Teepee Pole site
Bearberry
Highway 734 (gravel)
Highway 584 (gravel)
Highway 584
Sundre
N
Edmonton
Calgary

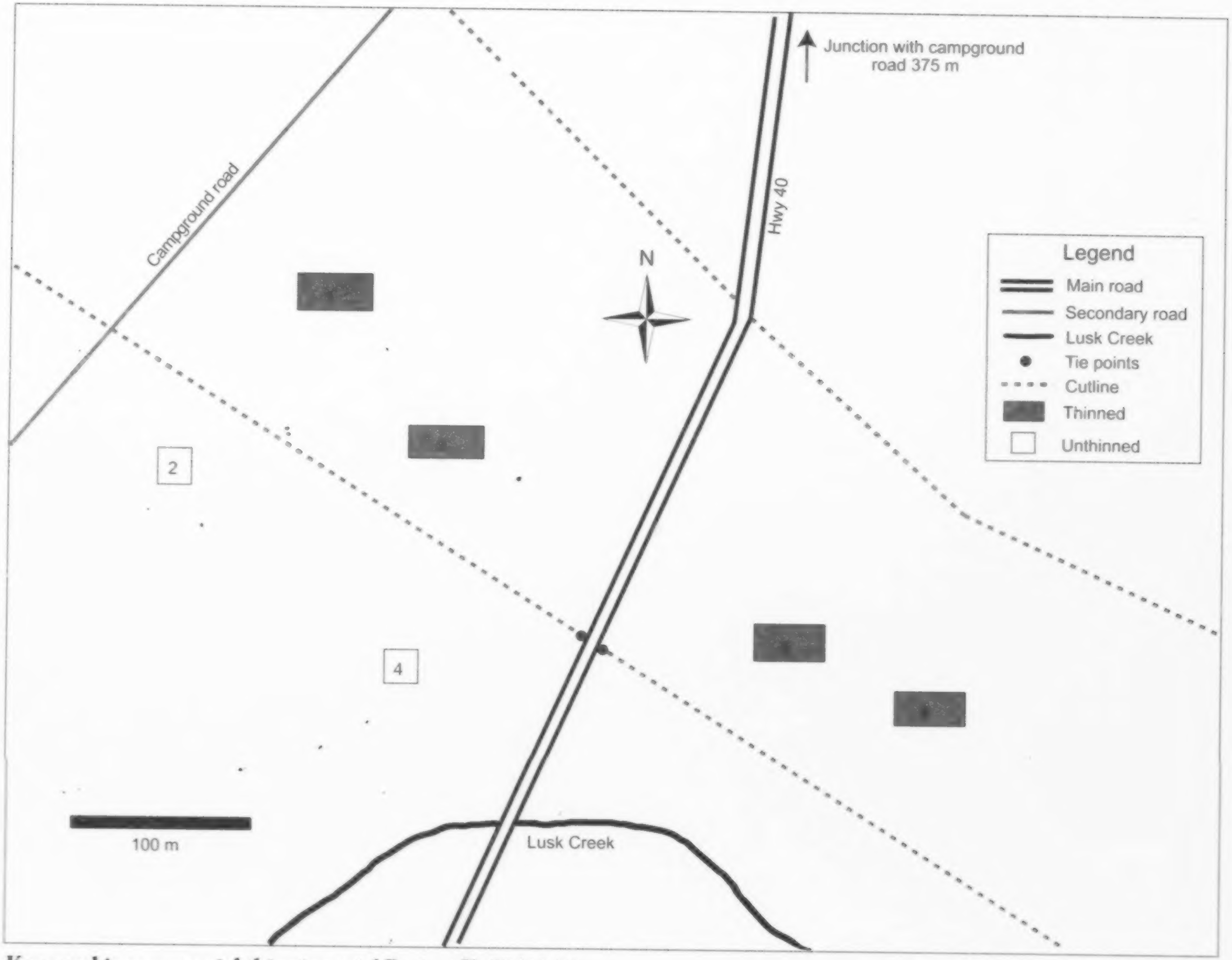
Historic pine trial access map—Rocky Mountain House region.


MacKay
Leaman
Chip Lake
Nojack
Highway 16
Little Brule Creek
Range Road 113
MacKay plots
N
Streams
Highway
Waterbody
Limited-use road
Wetland
Road
0 0.5 1 2 3 4
km
Edmonton
Calgary
☐ MacKay region

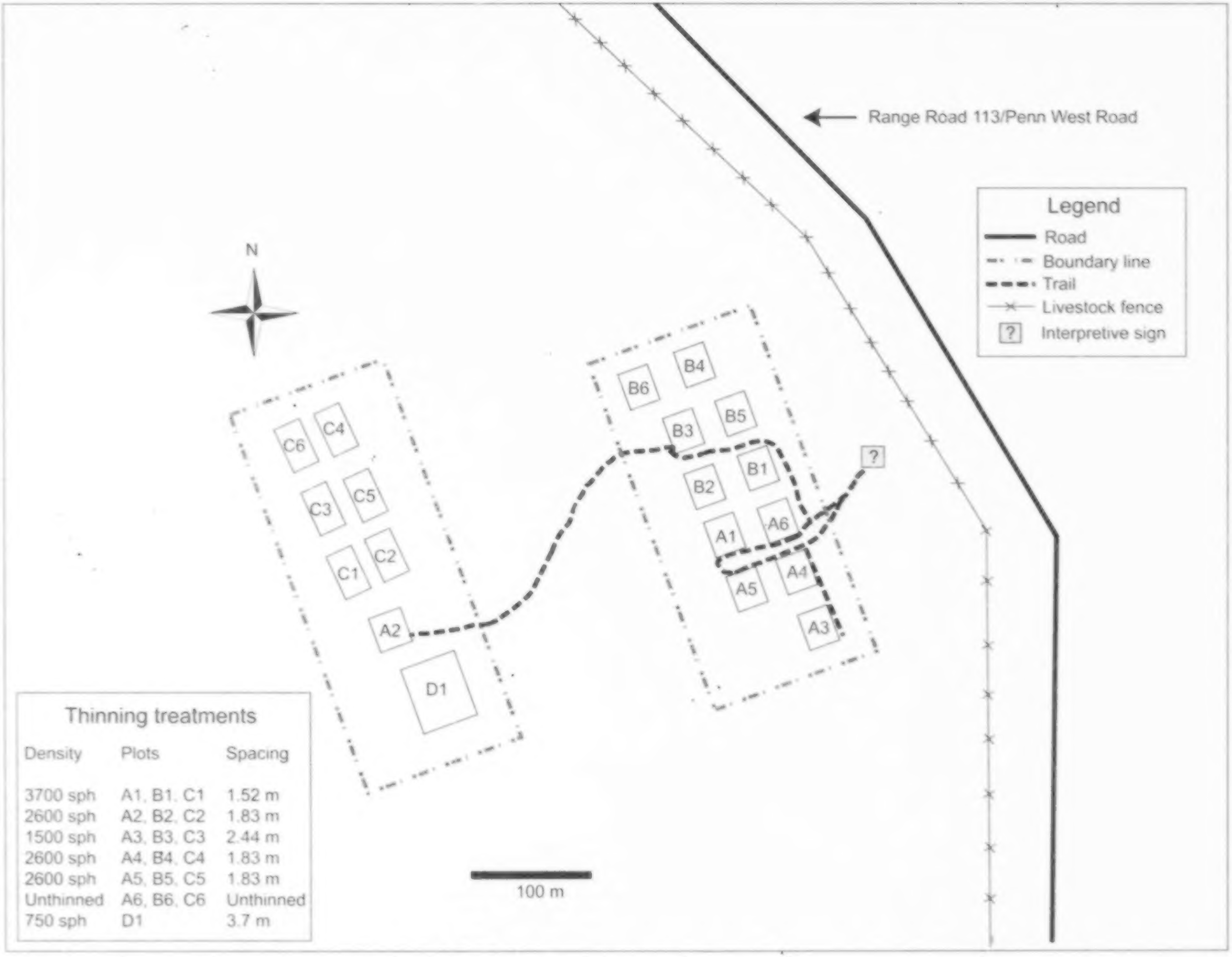
Historic pine trial access map—MacKay region.

Appendix 3

Site layout maps for each trial


Junction with campground road 375 m
Campground road
Hwy 40
N
Legend
Main road
Secondary road
Lusk Creek
Tie points
Cutline
Thinned
Unthinned
2
4
100 m
Lusk Creek

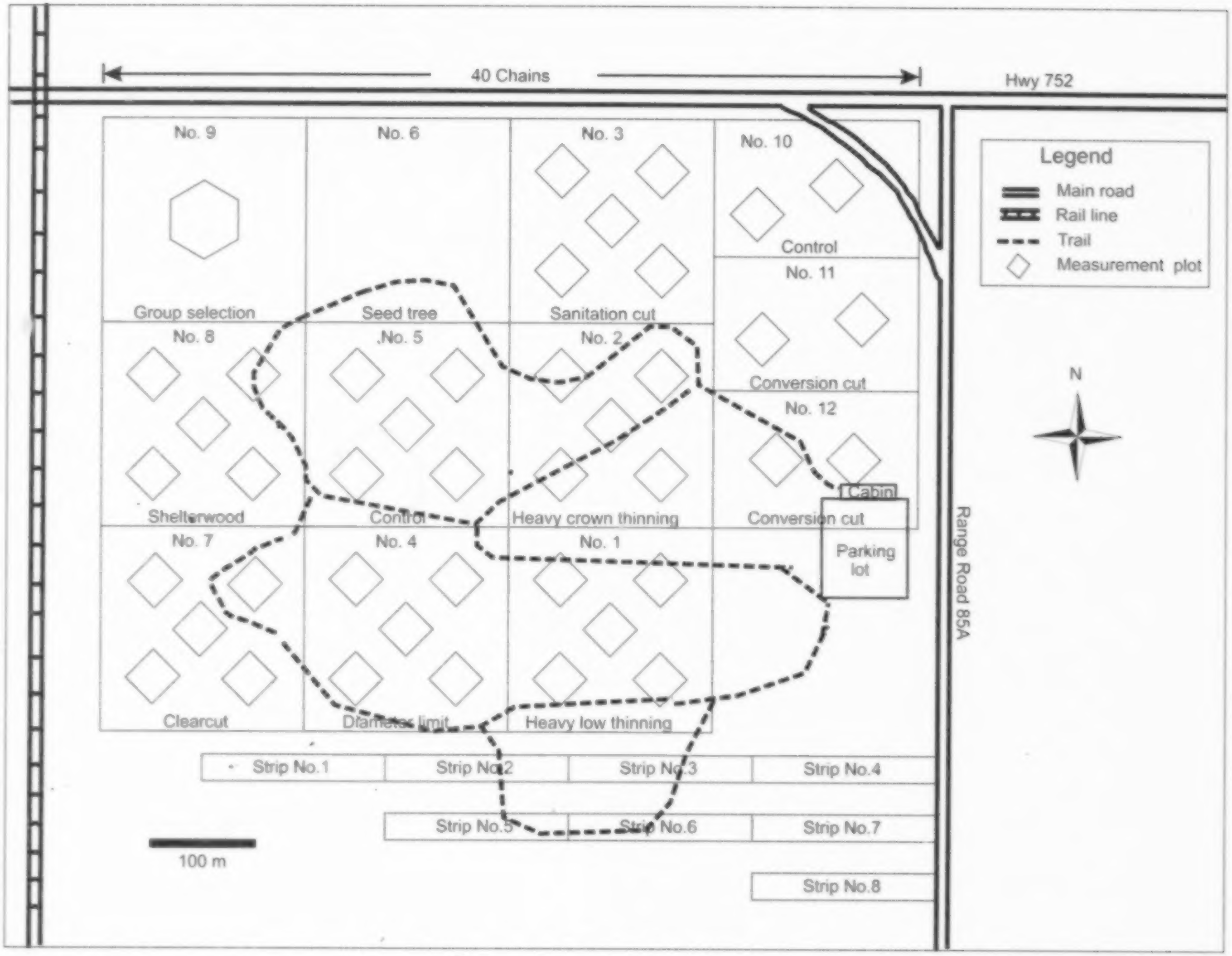
Kananaskis commercial thinning trial Project K-57 (1941).


Range Road 113/Penn West Road
Legend
Road
Boundary line
Trail
Livestock fence
? Interpretive sign
N
B6
B4
B3
B5
B2
B1
A1
A6
A5
A4
A3
?
C6
C4
C3
C5
C1
C2
A2
D1
100 m

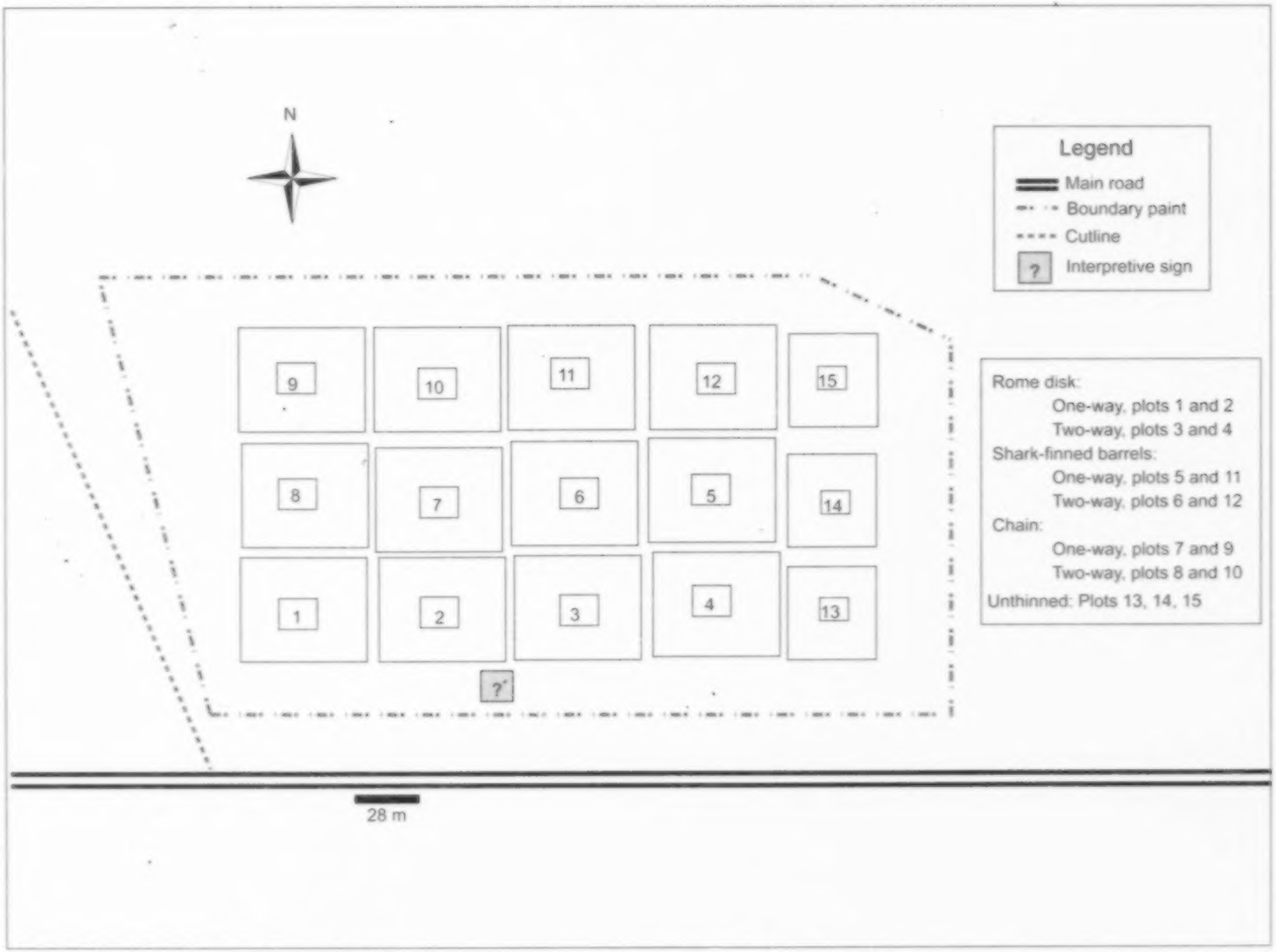
Thinning treatments

Density	Plots	Spacing
3700 sph	A1, B1, C1	1.52 m
2600 sph	A2, B2, C2	1.83 m
1500 sph	A3, B3, C3	2.44 m
2600 sph	A4, B4, C4	1.83 m
2600 sph	A5, B5, C5	1.83 m
Unthinned	A6, B6, C6	Unthinned
750 sph	D1	3.7 m

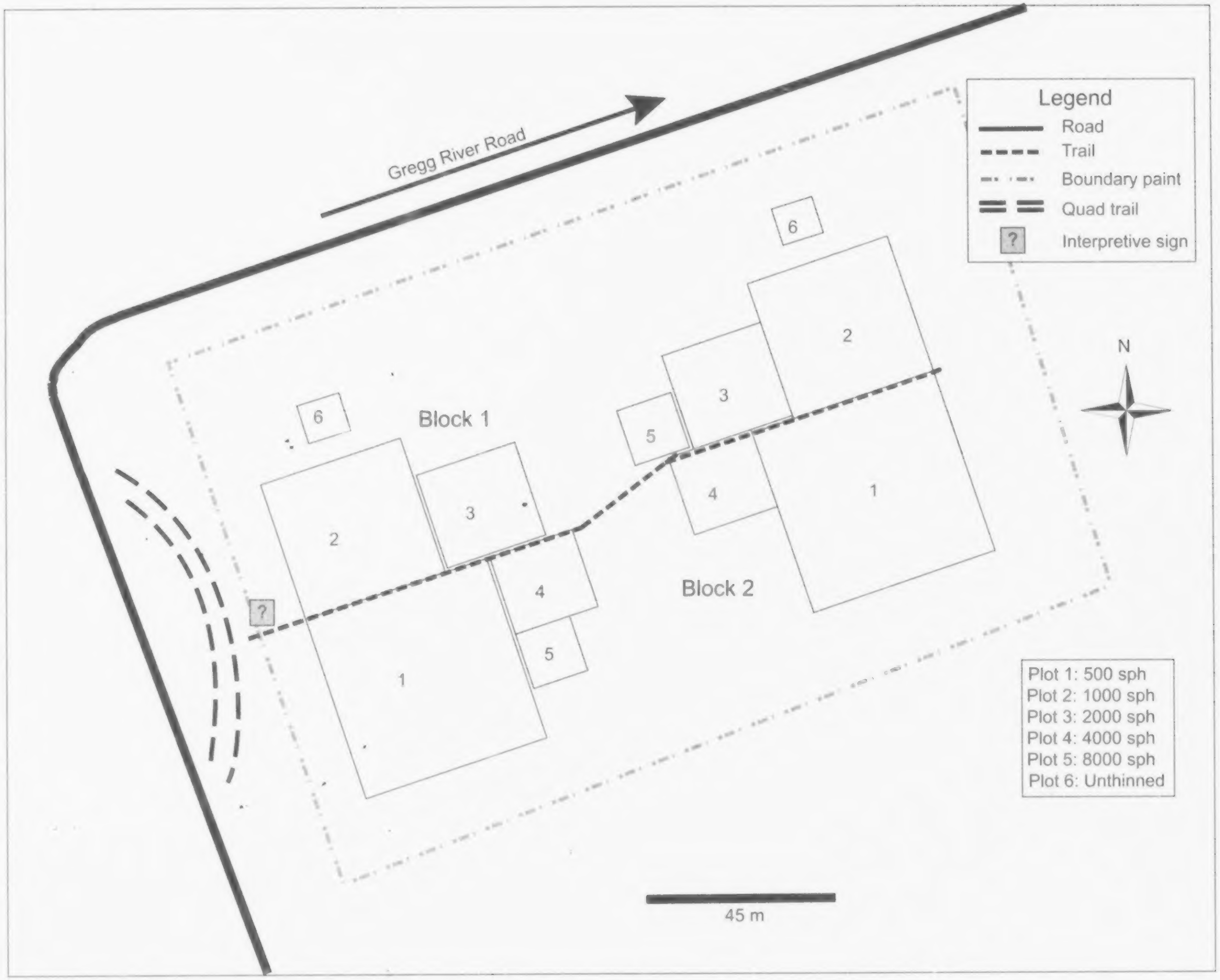
MacKay thinning experiment—Project A-34 (1954). Note: sph = stems per hectare.


40 Chains
Hwy 752
No. 9
No. 6
No. 3
No. 10
Control
Legend
Main road
Rail line
Trail
Measurement plot
Group selection
Seed tree
Sanitation cut
No. 11
No. 8
No. 5
No. 2
Conversion cut
No. 12
N
Shelterwood
Control
Heavy crown thinning
Cabin
Conversion cut
No. 7
No. 4
No. 1
Parking lot
Range Road 85A
Clearcut
Diameter limit
Heavy low thinning
Strip No.1
Strip No.2
Strip No.3
Strip No.4
Strip No.5
Strip No.6
Strip No.7
100 m
Strip No.8

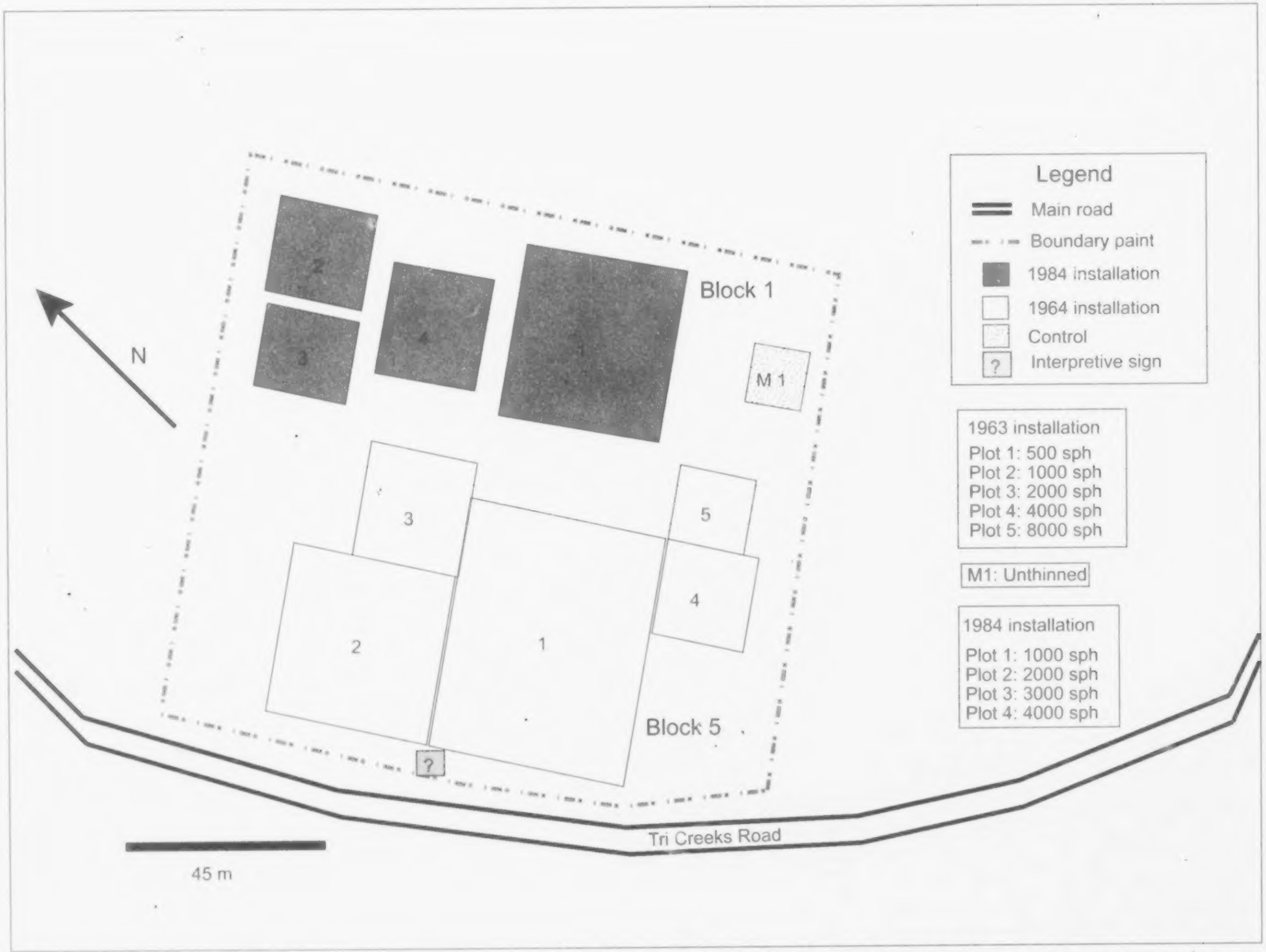
Strachan thinning trial (1951).


N
Legend
Main road
Boundary paint
Cutline
?
Interpretive sign
9
10
11
12
15
8
7
6
5
14
1
2
3
4
13
?
28 m
Rome disk:
One-way, plots 1 and 2
Two-way, plots 3 and 4
Shark-finned barrels:
One-way, plots 5 and 11
Two-way, plots 6 and 12
Chain:
One-way, plots 7 and 9
Two-way, plots 8 and 10
Unthinned: Plots 13, 14, 15

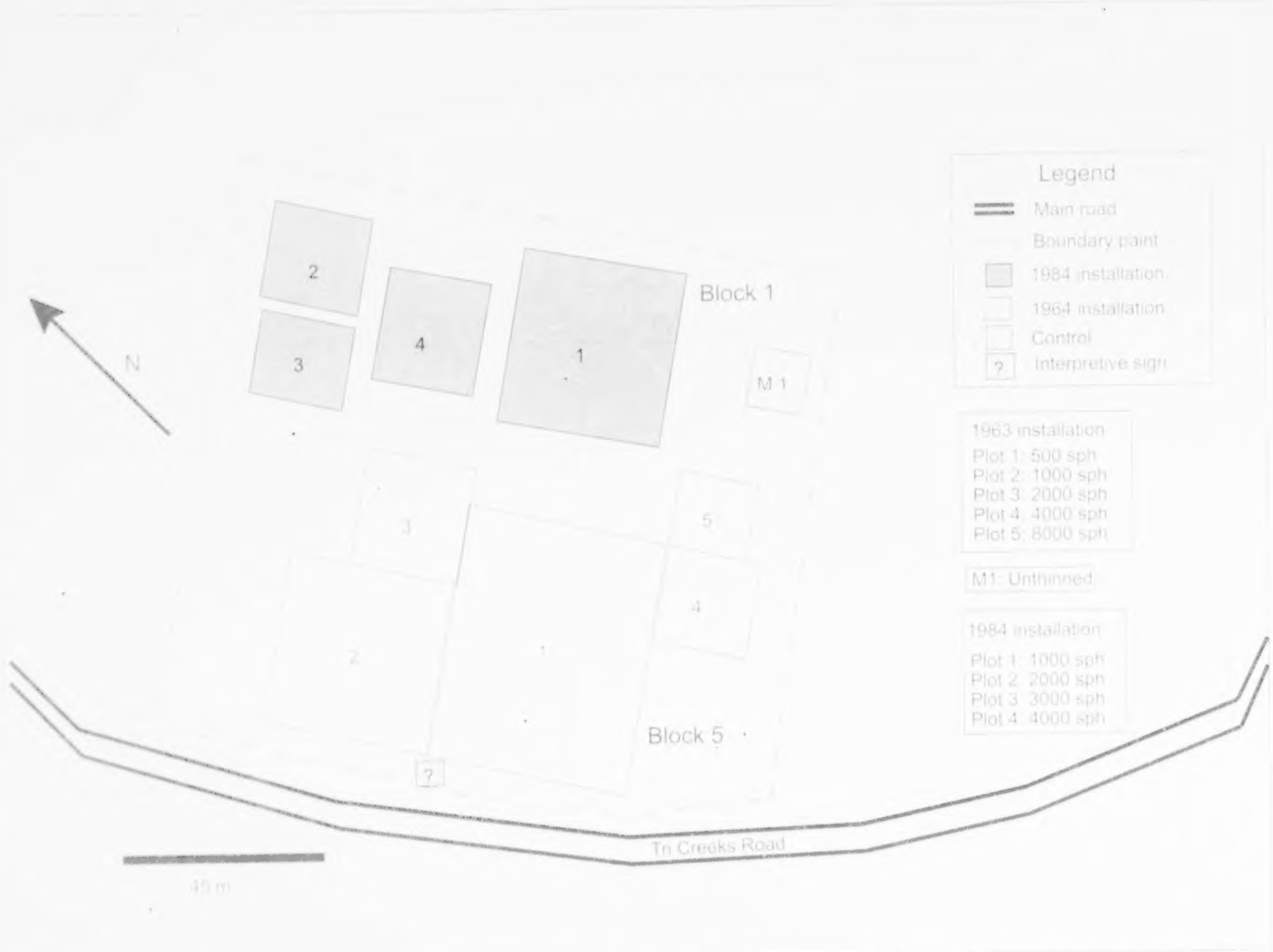
Swan Lake thinning experiment 1976.


Gregg River Road
Legend
Road
Trail
Boundary paint
Quad trail
?
Interpretive sign
N
Block 1
Block 2
1
2
3
4
5
6
1
2
3
4
5
6
?
Plot 1: 500 sph
Plot 2: 1000 sph
Plot 3: 2000 sph
Plot 4: 4000 sph
Plot 5: 8000 sph
Plot 6: Unthinned
45 m

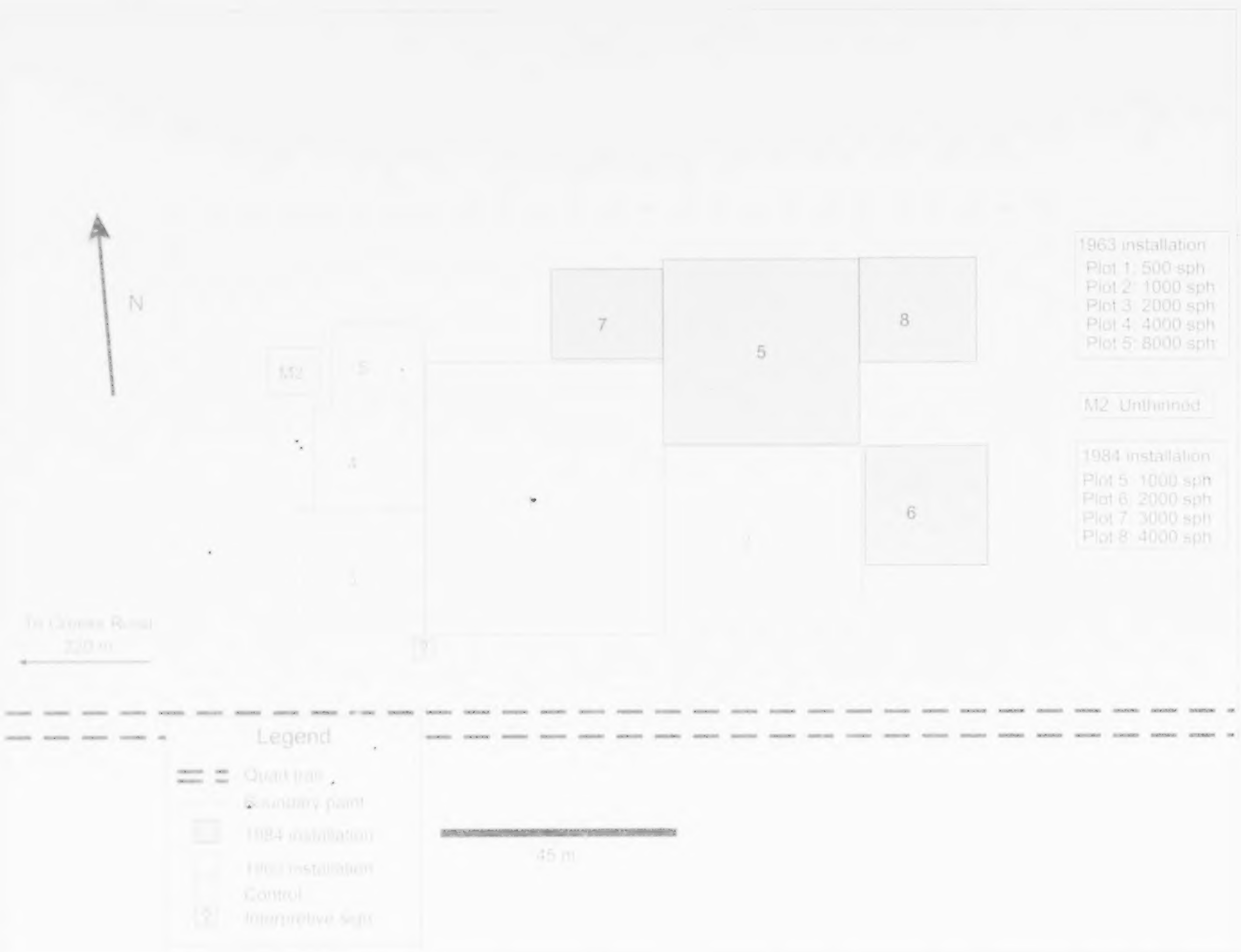
Gregg Burn 1963 spacing experiment—low productivity site. Note: sph = stems per hectare.


N
Block 1
Block 5
2
3
4
1
M 1
3
5
1
4
2
?
Tri Creeks Road
45 m
Legend
Main road
Boundary paint
1984 installation
1964 installation
Control
Interpretive sign
1963 installation
Plot 1: 500 sph
Plot 2: 1000 sph
Plot 3: 2000 sph
Plot 4: 4000 sph
Plot 5: 8000 sph
M1: Unthinned
1984 installation
Plot 1: 1000 sph
Plot 2: 2000 sph
Plot 3: 3000 sph
Plot 4: 4000 sph

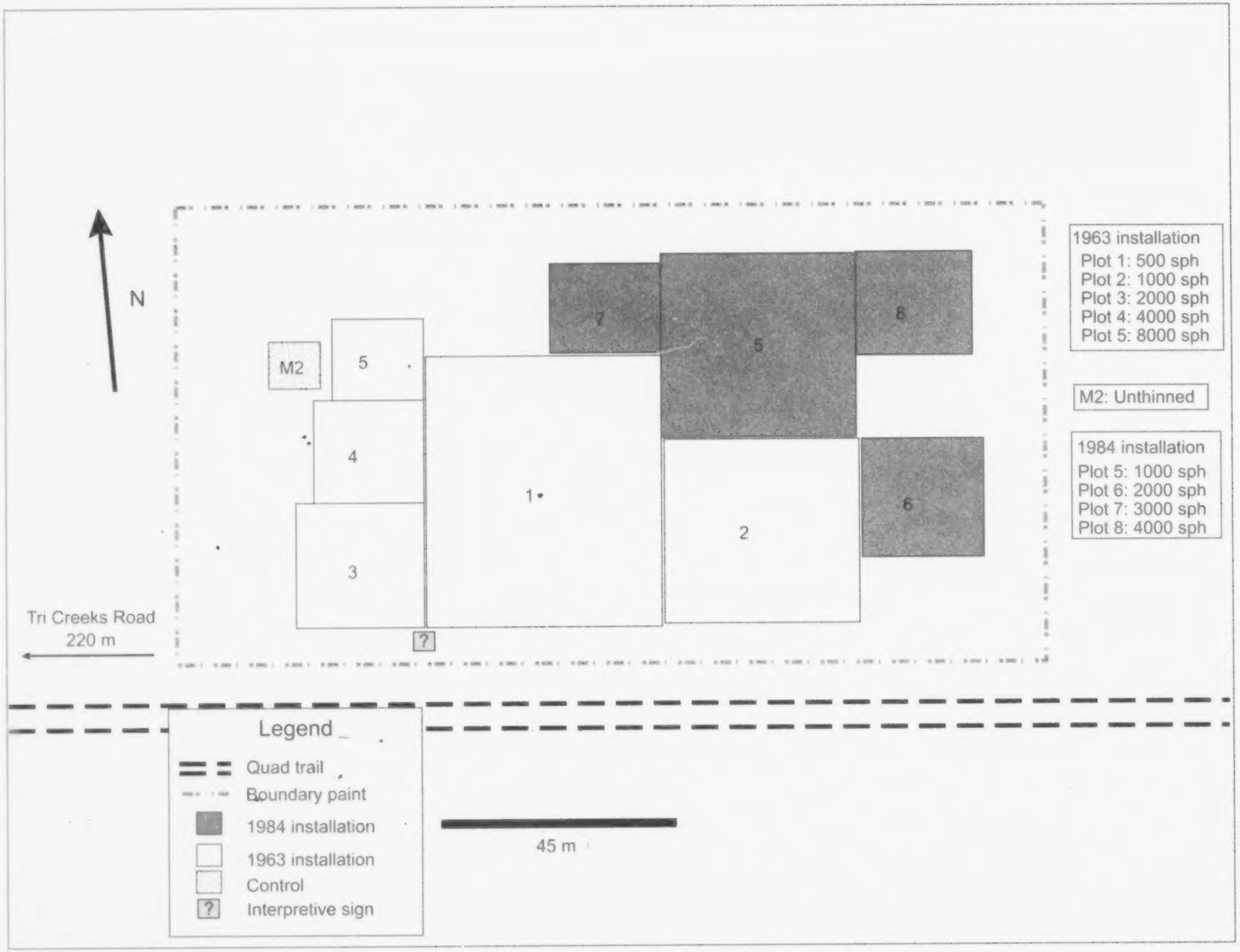
Gregg Burn 1963 and 1984 spacing experiments— medium productivity site, replicate 1. Note: sph = stems per hectare.


N
2
3
4
1
Block 1
M 1
3
5
2
1
4
Block 5
?
Tn Creeks Road
45 m
Legend
Main road
Boundary paint
1984 installation
1964 installation
Control
? Interpretive sign
1963 installation
Plot 1: 500 sph
Plot 2: 1000 sph
Plot 3: 2000 sph
Plot 4: 4000 sph
Plot 5: 8000 sph
M1: Unthinned
1984 installation
Plot 1: 1000 sph
Plot 2: 2000 sph
Plot 3: 3000 sph
Plot 4: 4000 sph

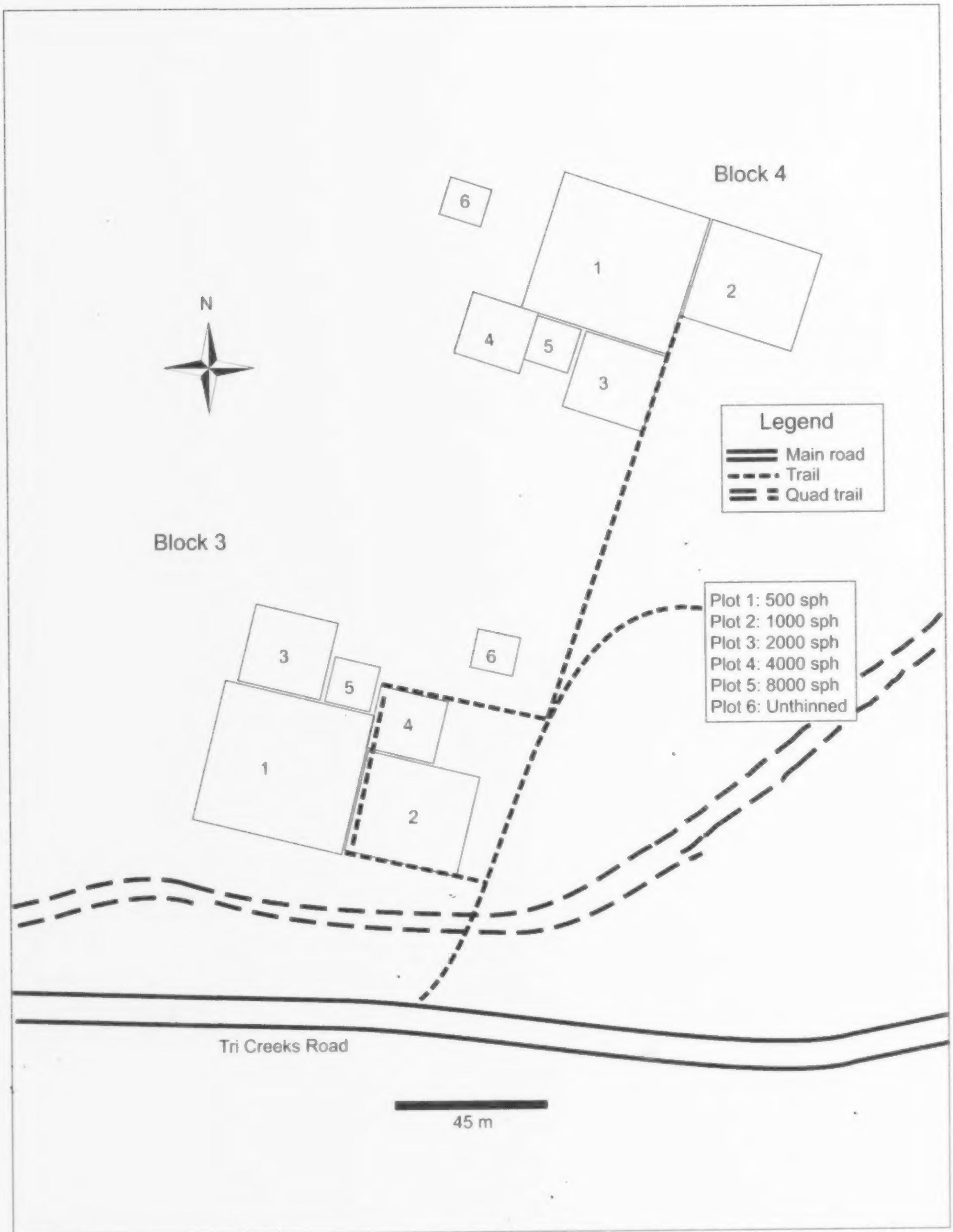
Gregg Burn 1963 and 1984 spacing experiments— **medium productivity site, replicate 1.** Note: sph = stems per hectare.


N
M2
5
4
3
7
5
8
6
2
220 m
1963 installation
Plot 1: 500 sph
Plot 2: 1000 sph
Plot 3: 2000 sph
Plot 4: 4000 sph
Plot 5: 8000 sph
M2: Unthinned
1984 installation
Plot 5: 1000 sph
Plot 6: 2000 sph
Plot 7: 3000 sph
Plot 8: 4000 sph
Legend
Quad trail
Boundary paint
1984 installation
1963 installation
Control
Interpretive sign
45 m

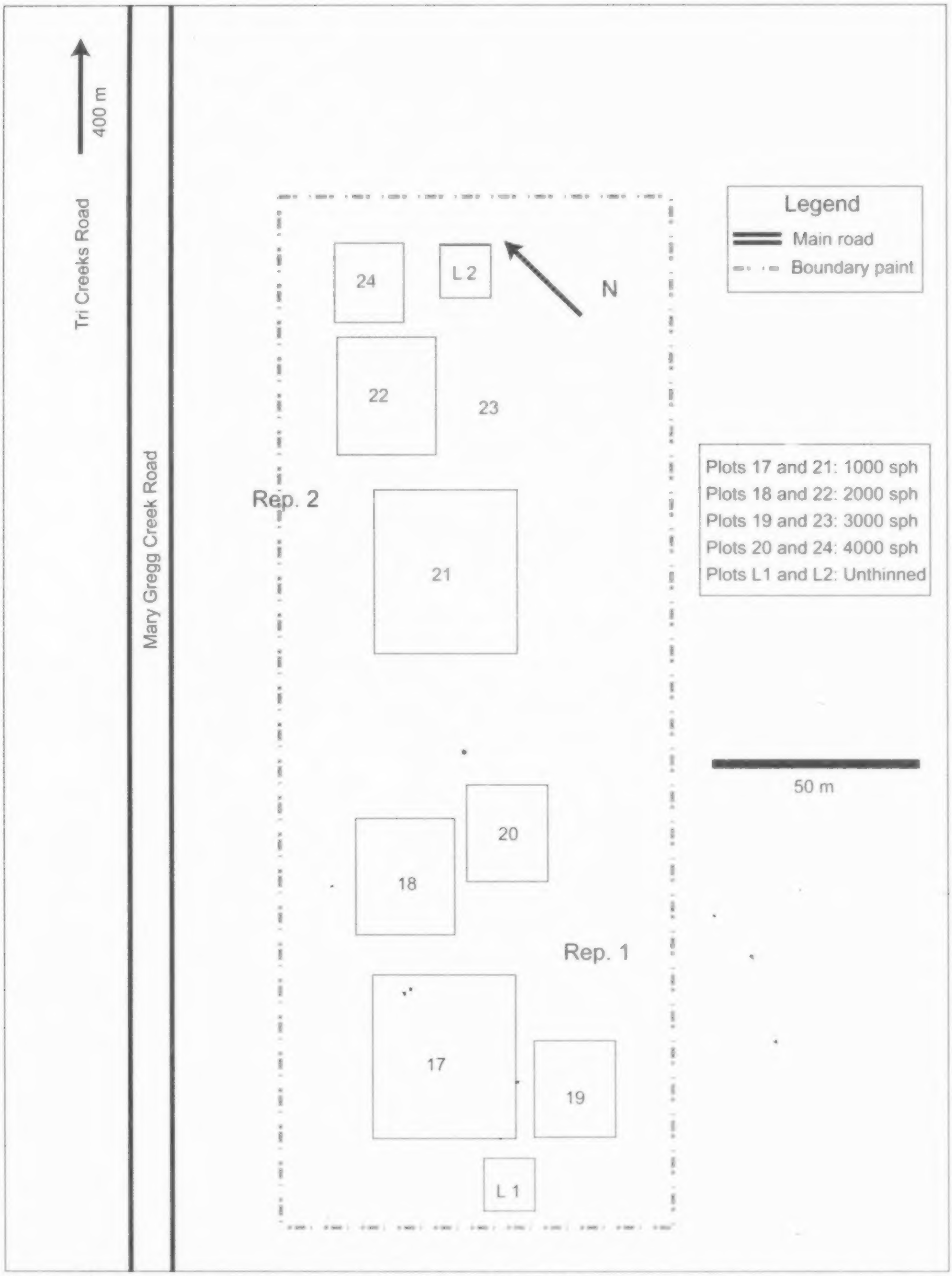
Gregg spacing 1963 and 1984 experiments—medium productivity site, replicate 2. Note: sph = stems per hectare.


N
Tri Creeks Road
220 m
M2
5
4
3
1
2
7
5
8
6
?
1963 installation
Plot 1: 500 sph
Plot 2: 1000 sph
Plot 3: 2000 sph
Plot 4: 4000 sph
Plot 5: 8000 sph
M2: Unthinned
1984 installation
Plot 5: 1000 sph
Plot 6: 2000 sph
Plot 7: 3000 sph
Plot 8: 4000 sph
Legend
Quad trail
Boundary paint
1984 installation
1963 installation
Control
Interpretive sign
45 m

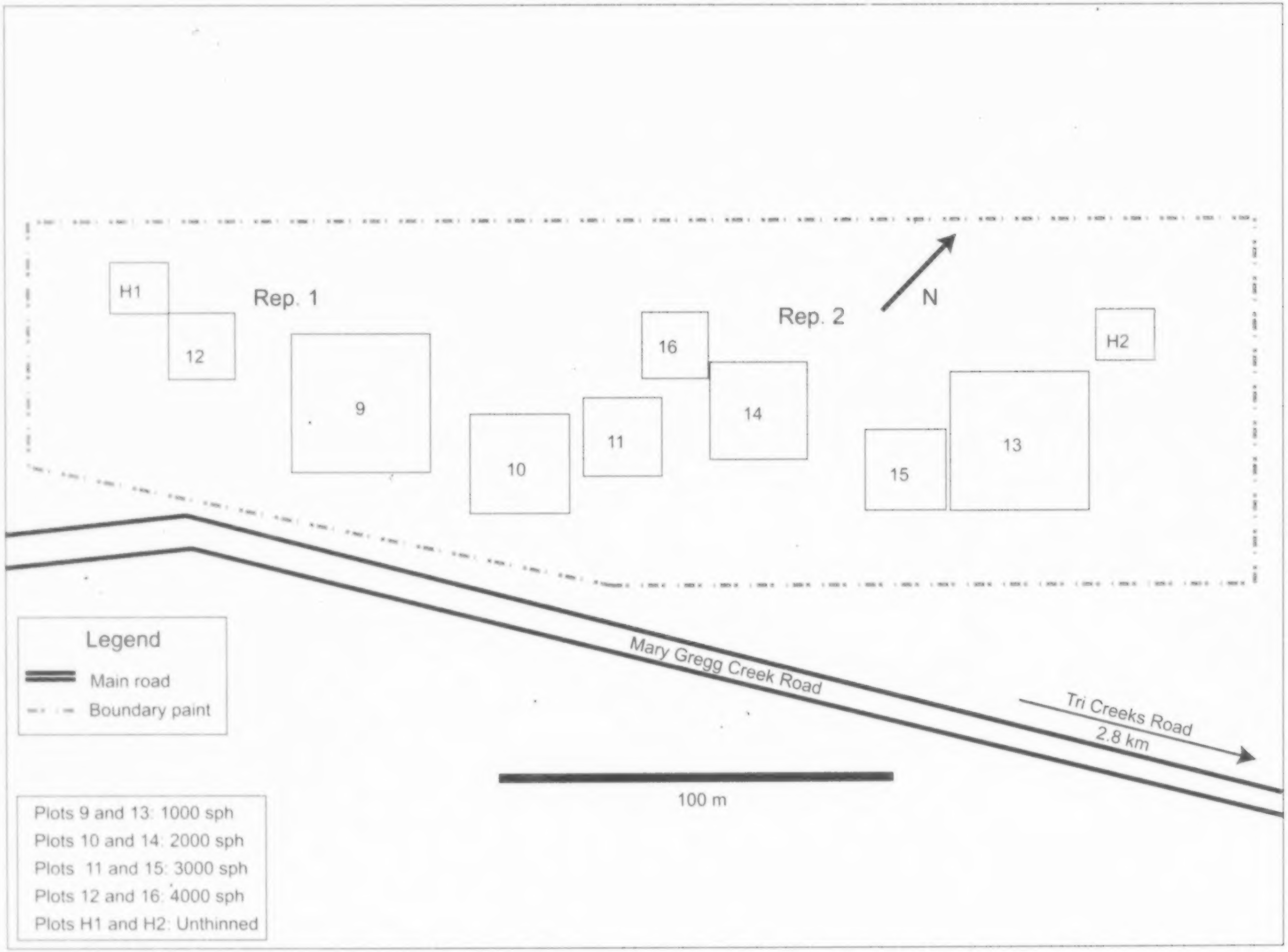
Gregg spacing 1963 and 1984 experiments—medium productivity site, replicate 2. Note: sph = stems per hectare.


Block 4
6
1
2
4
5
3
N
Legend
Main road
Trail
Quad trail
Block 3
Plot 1: 500 sph
Plot 2: 1000 sph
Plot 3: 2000 sph
Plot 4: 4000 sph
Plot 5: 8000 sph
Plot 6: Unthinned
3
5
6
4
1
2
Tri Creeks Road
45 m

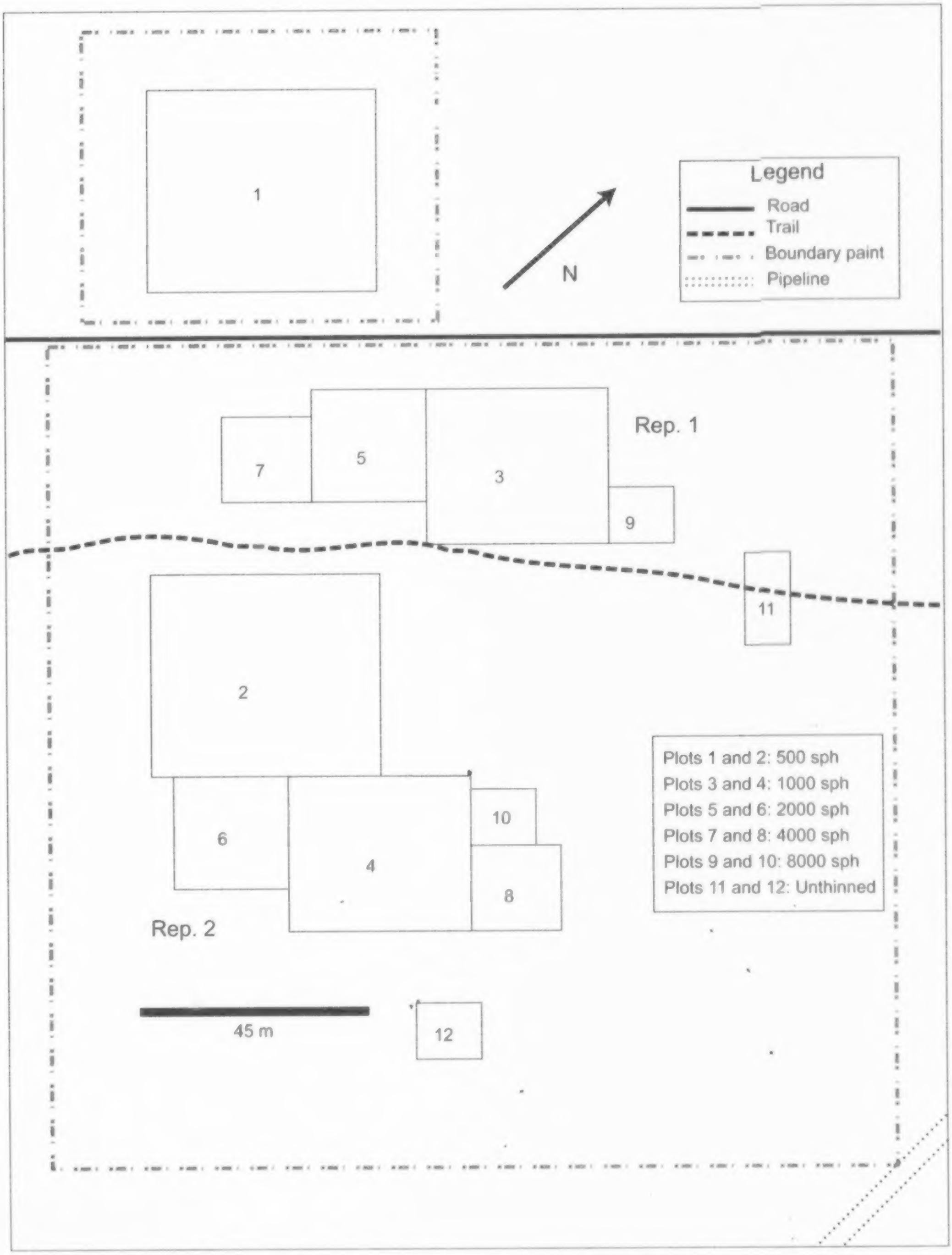
Gregg Burn 1963 spacing experiment—high productivity site. Note: sph = stems per hectare.


400 m
Tri Creeks Road
Mary Gregg Creek Road
Legend
Main road
Boundary paint
24
L 2
N
22
23
Rep. 2
21
Plots 17 and 21: 1000 sph
Plots 18 and 22: 2000 sph
Plots 19 and 23: 3000 sph
Plots 20 and 24: 4000 sph
Plots L1 and L2: Unthinned
50 m
20
18
Rep. 1
17
19
L 1

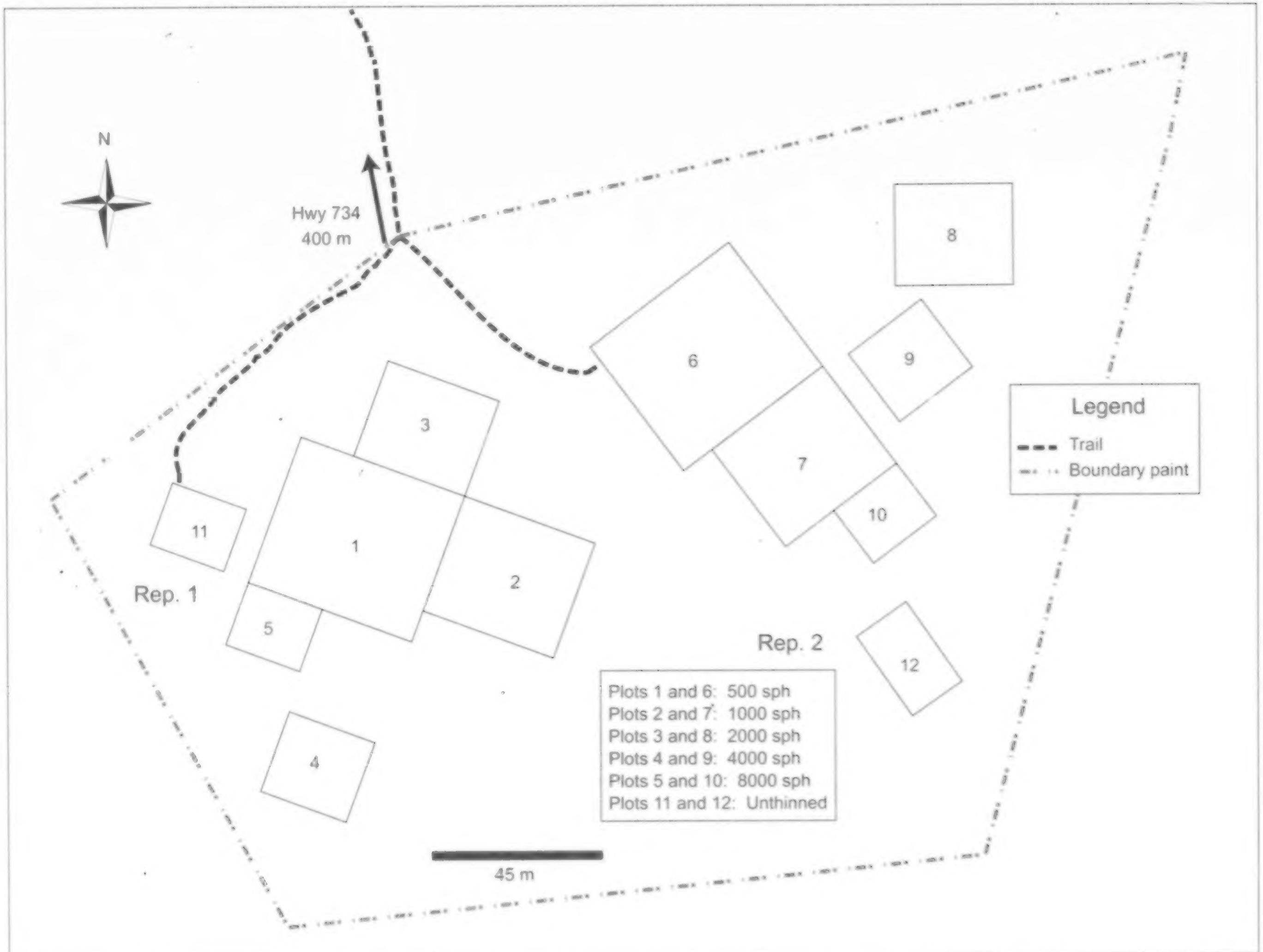
Gregg Burn spacing experiment 1984—low productivity site. Note: sph = stems per hectare.


Rep. 1
Rep. 2
N
H1
12
9
10
11
16
14
15
13
H2
Mary Gregg Creek Road
Tri Creeks Road
2.8 km
100 m
Legend
Main road
Boundary paint
Plots 9 and 13: 1000 sph
Plots 10 and 14: 2000 sph
Plots 11 and 15: 3000 sph
Plots 12 and 16: 4000 sph
Plots H1 and H2: Unthinned

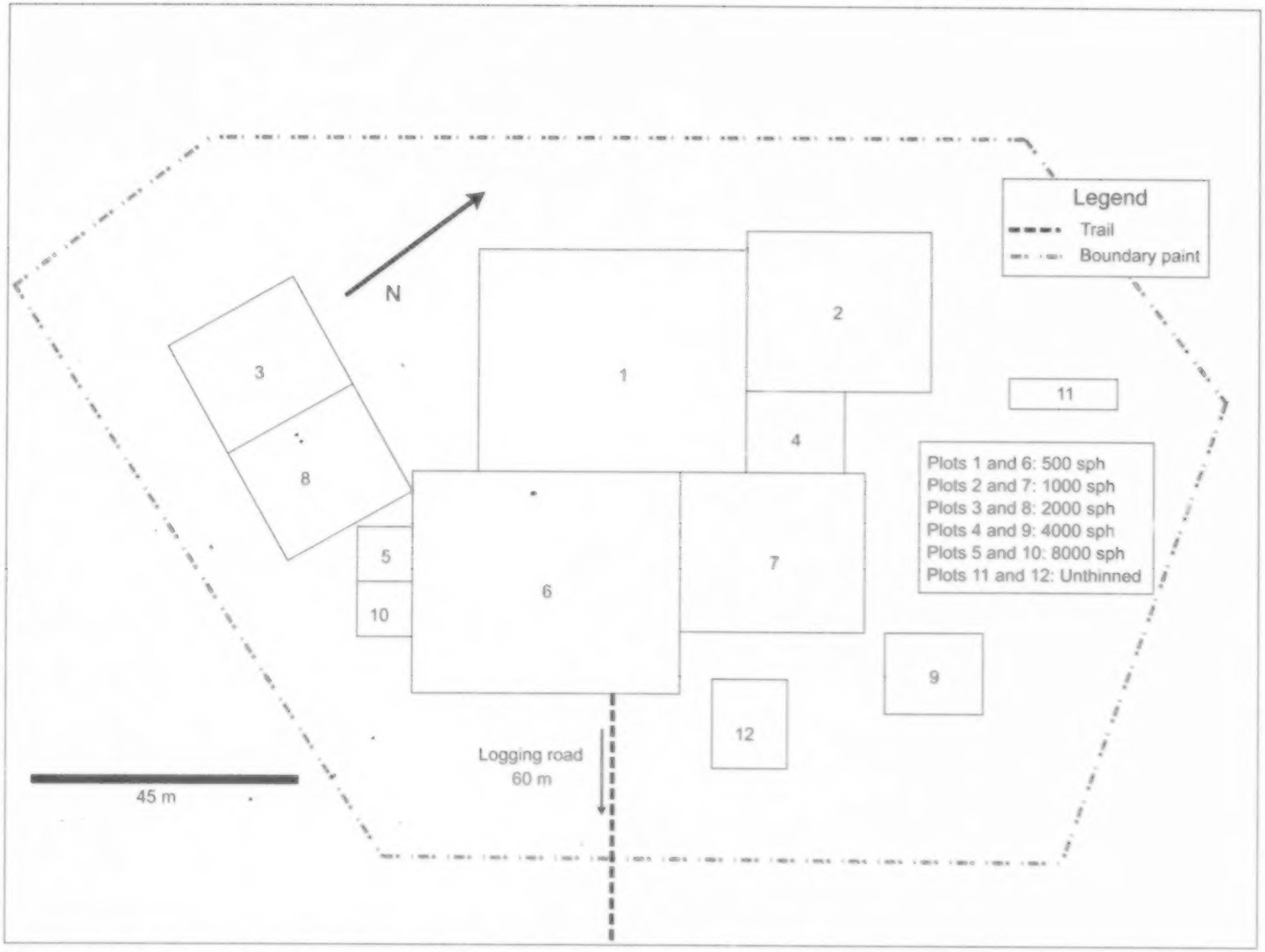
Gregg Burn 1984 spacing experiment—high productivity site. Note: sph = stems per hectare.


Legend
Road
Trail
Boundary paint
Pipeline
N
1
7
5
3
9
Rep. 1
11
2
6
4
10
8
Rep. 2
45 m
12
Plots 1 and 2: 500 sph
Plots 3 and 4: 1000 sph
Plots 5 and 6: 2000 sph
Plots 7 and 8: 4000 sph
Plots 9 and 10: 8000 sph
Plots 11 and 12: Unthinned

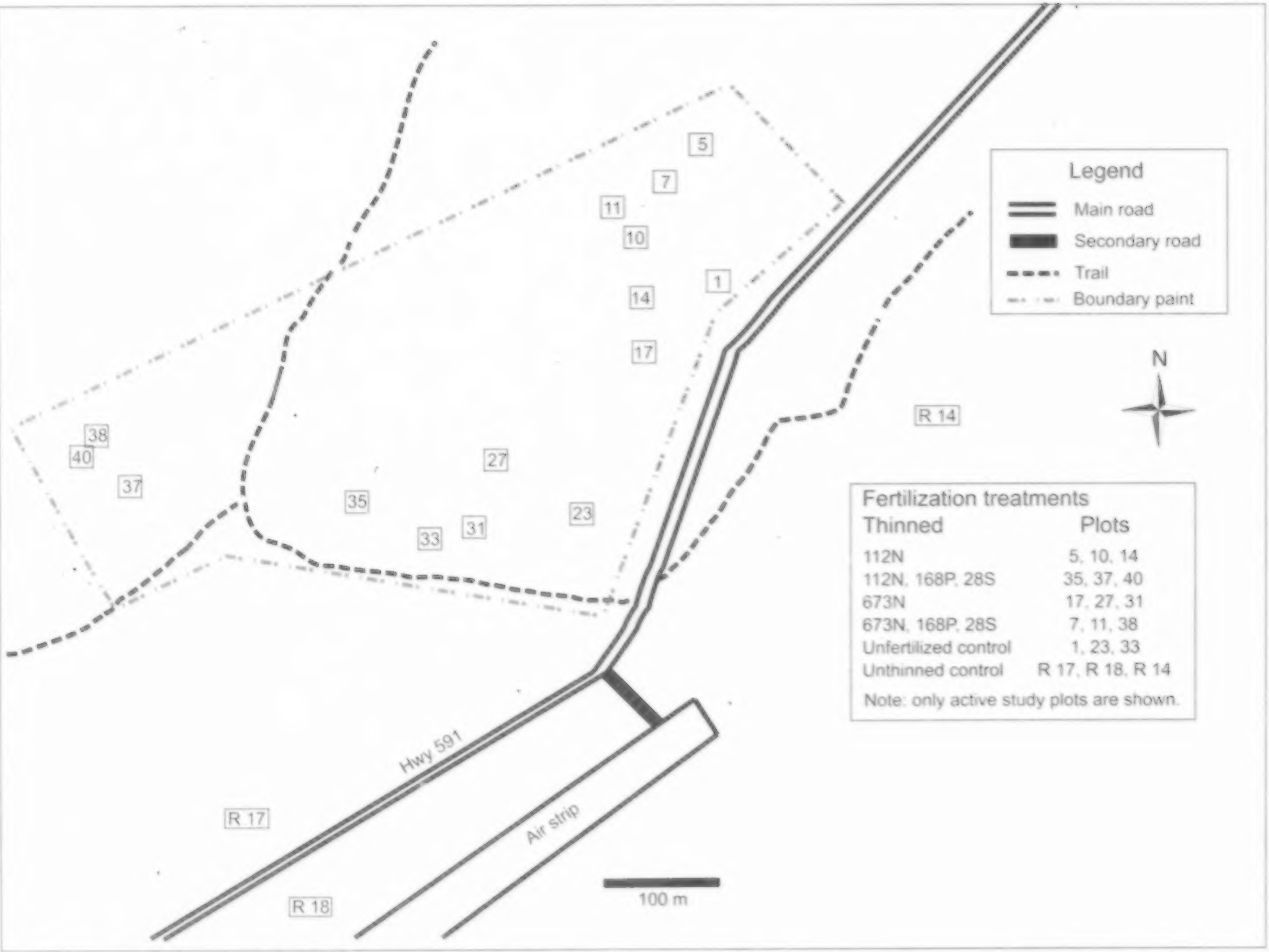
Teepee Pole Creek spacing experiment (1967)—flat site. Note: sph = stems per hectare.


N
Hwy 734
400 m
Legend
Trail
Boundary paint
8
6
9
3
7
10
11
1
2
Rep. 1
5
Rep. 2
12
4
Plots 1 and 6: 500 sph
Plots 2 and 7: 1000 sph
Plots 3 and 8: 2000 sph
Plots 4 and 9: 4000 sph
Plots 5 and 10: 8000 sph
Plots 11 and 12: Unthinned
45 m

Teepee Pole Creek spacing experiment (1967)—north site. Note: sph = stems per hectare.


Legend
Trail
Boundary paint
N
1
2
3
4
5
6
7
8
9
10
11
12
Plots 1 and 6: 500 sph
Plots 2 and 7: 1000 sph
Plots 3 and 8: 2000 sph
Plots 4 and 9: 4000 sph
Plots 5 and 10: 8000 sph
Plots 11 and 12: Unthinned
Logging road
60 m
45 m

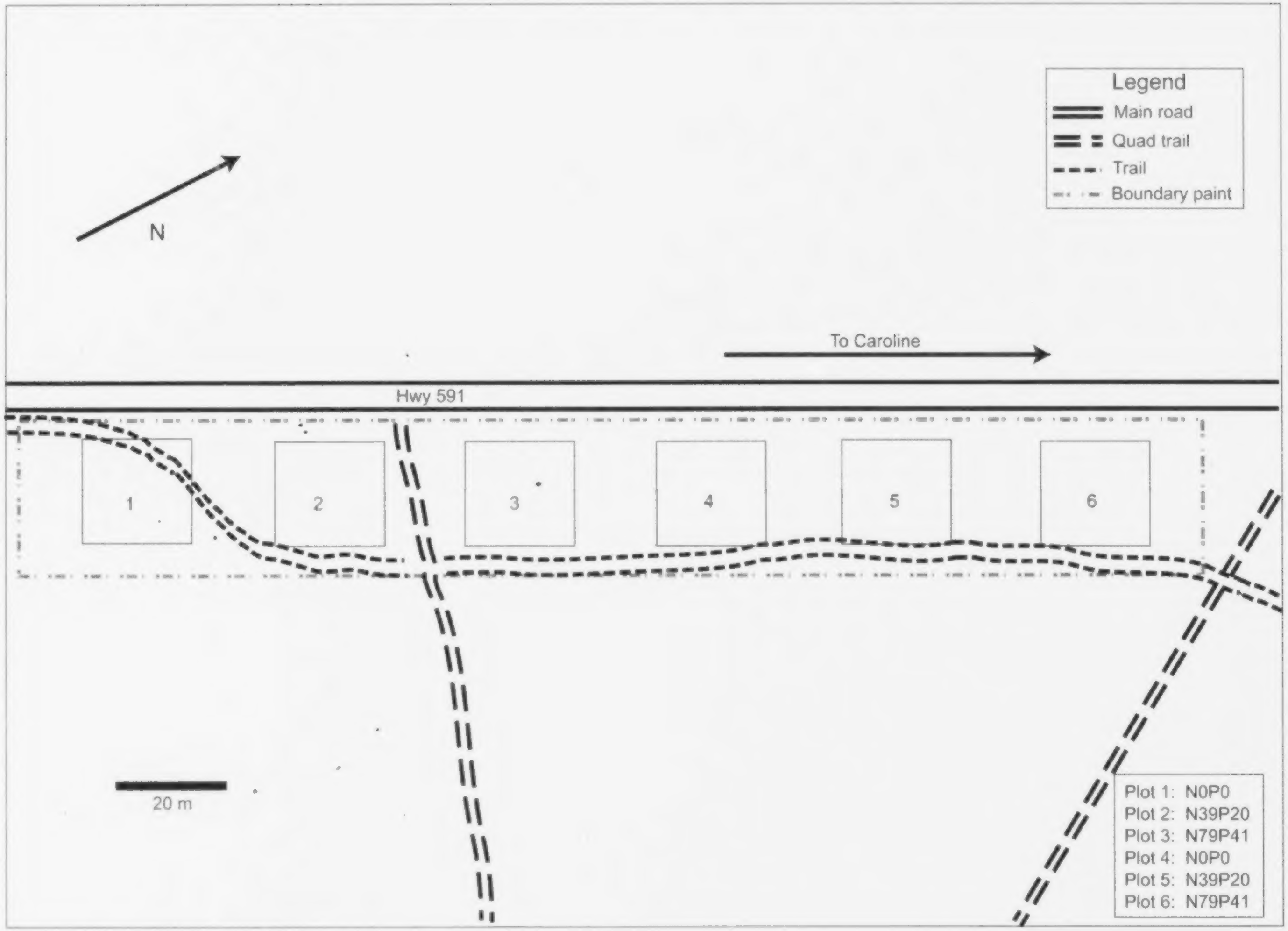
Teepee Pole Creek spacing experiment (1967)—south site. Note: sph = stems per hectare.


Legend
Main road
Secondary road
Trail
Boundary paint
N
5
7
11
10
1
14
17
38
40
37
27
35
23
31
33
R 14
R 17
R 18
Hwy 591
Air strip
100 m

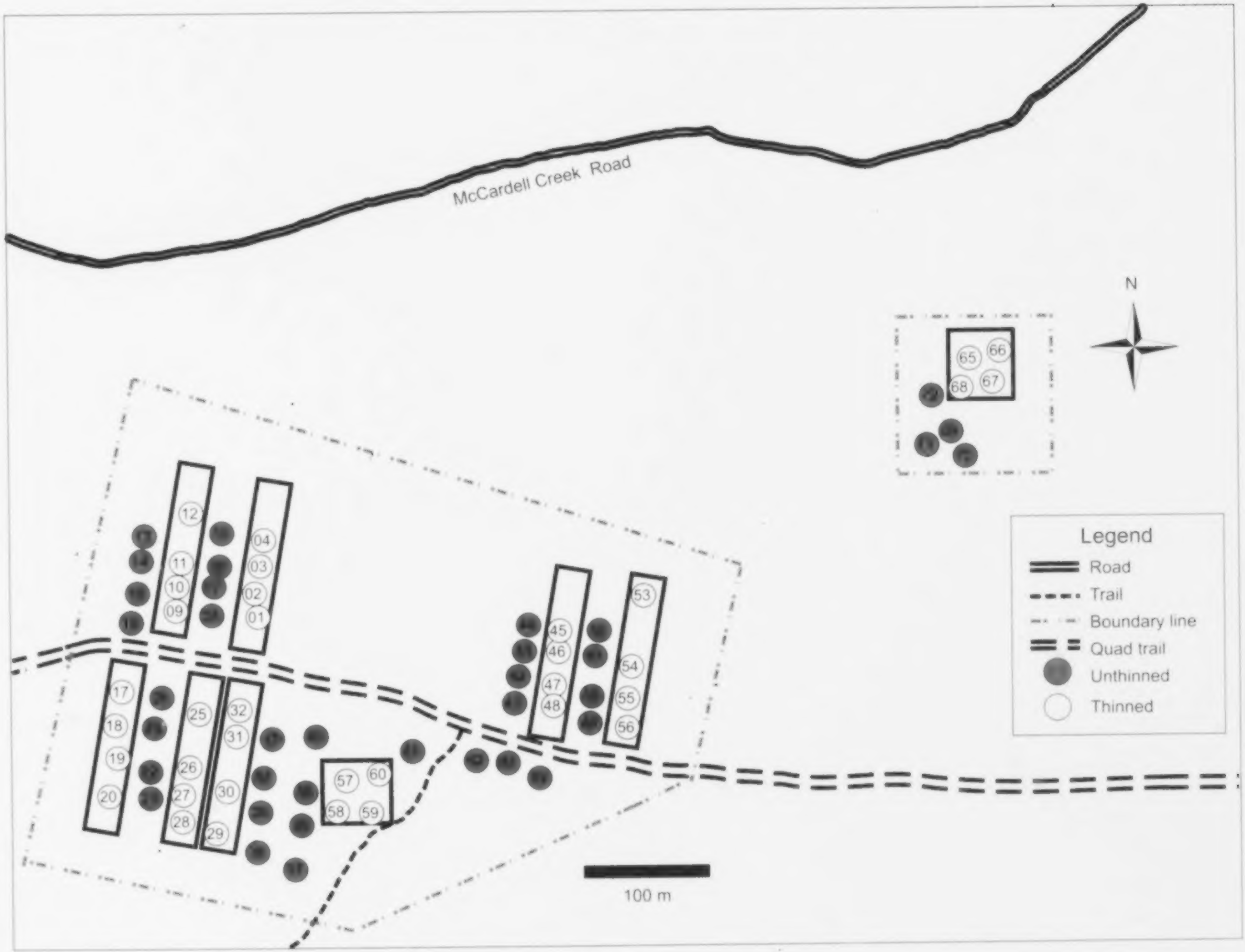
Fertilization treatments Thinned	Plots
112N	5, 10, 14
112N, 168P, 28S	35, 37, 40
673N	17, 27, 31
673N, 168P, 28S	7, 11, 38
Unfertilized control	1, 23, 33
Unthinned control	R 17, R 18, R 14

Note: only active study plots are shown.

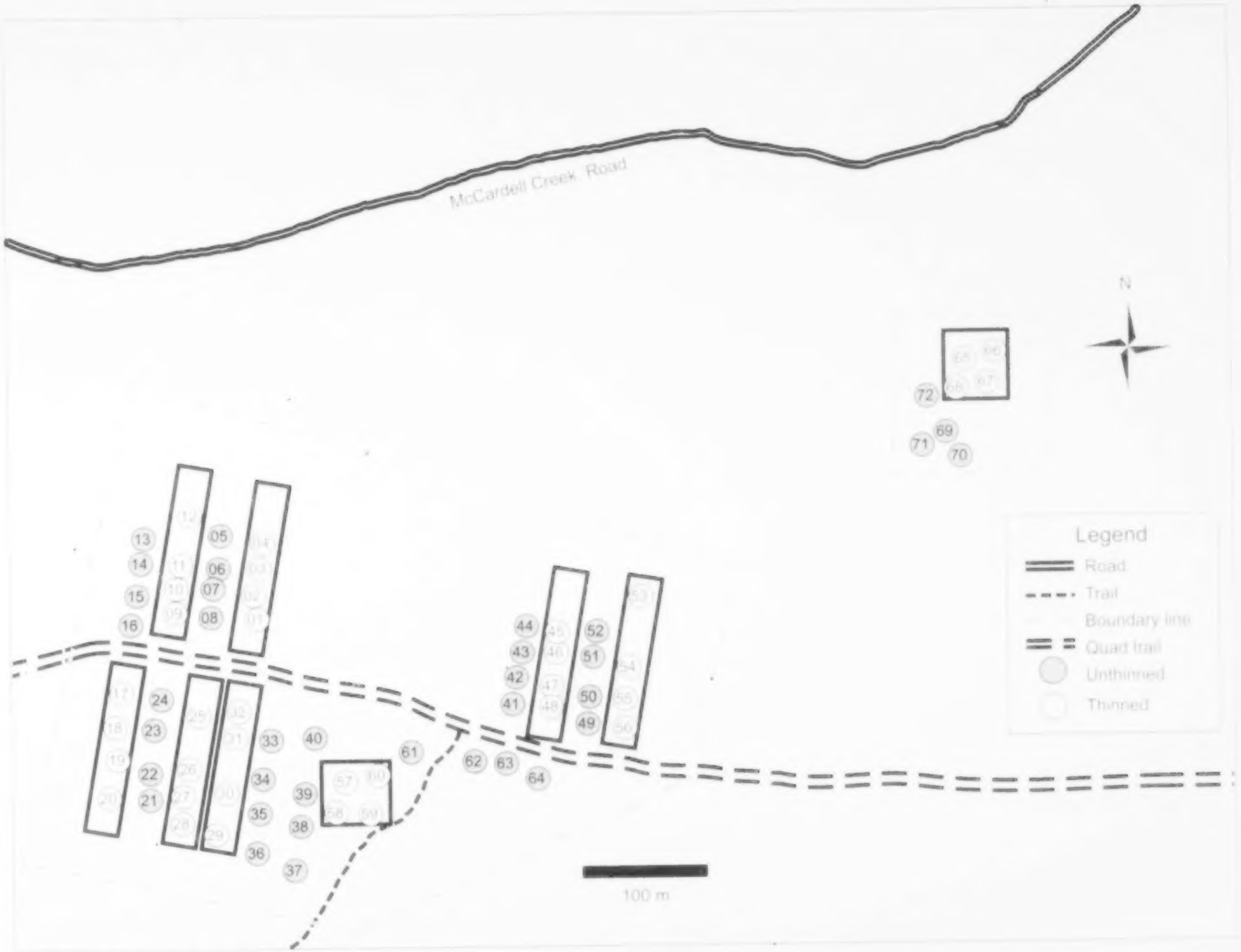
Clearwater fertilization and thinning experiment (1968).


Legend
Main road
Quad trail
Trail
Boundary paint
N
To Caroline
Hwy 591
1
2
3
4
5
6
20 m
Plot 1: N0P0
Plot 2: N39P20
Plot 3: N79P41
Plot 4: N0P0
Plot 5: N39P20
Plot 6: N79P41

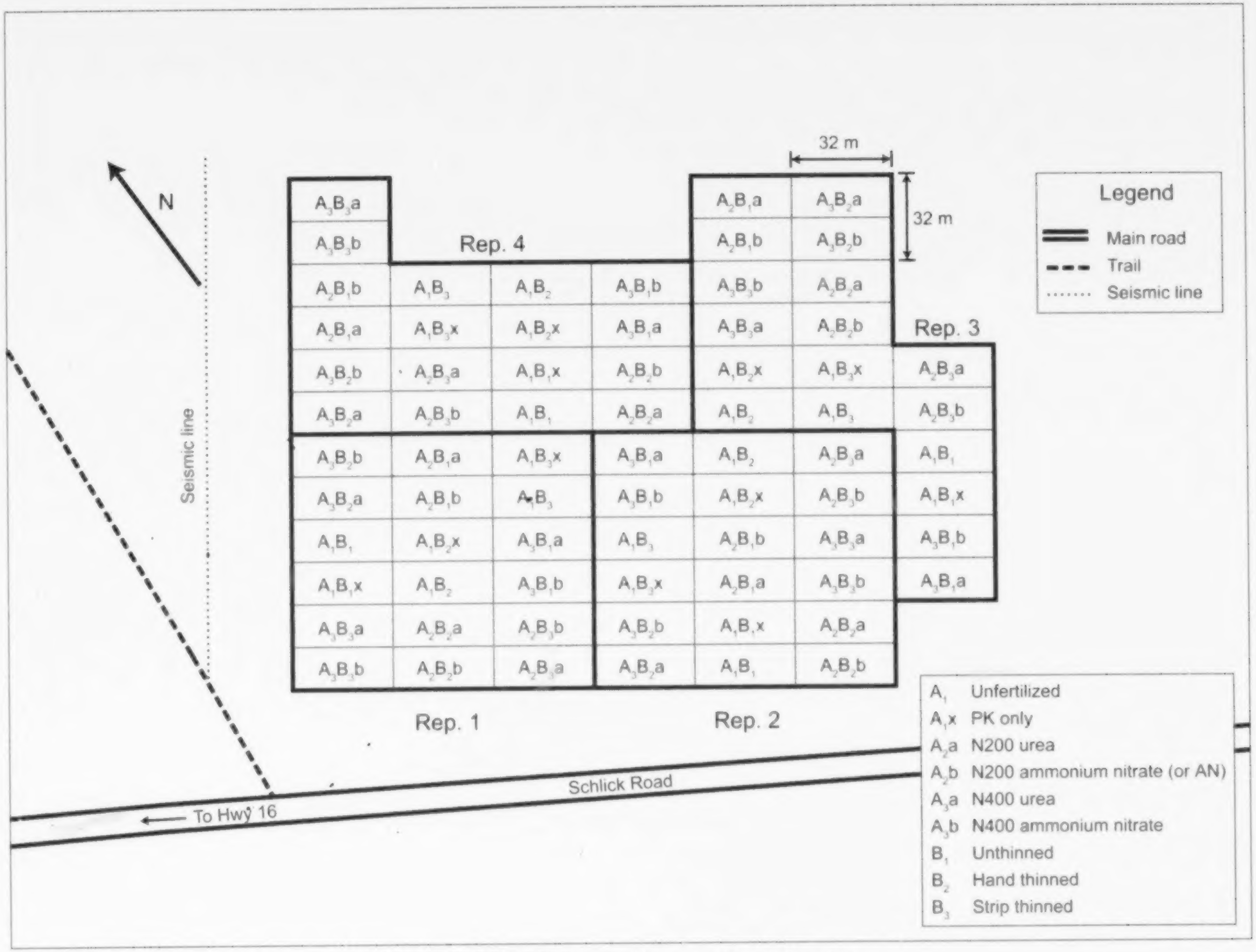
Ricinus fertilization trial (1965).


McCardell Creek Road
N
Legend
Road
Trail
Boundary line
Quad trail
Unthinned
Thinned
100 m
12
11
10
09
04
03
02
01
17
18
19
20
25
26
27
28
32
31
30
29
57
60
58
59
45
46
47
48
53
54
55
56
65
66
68
67

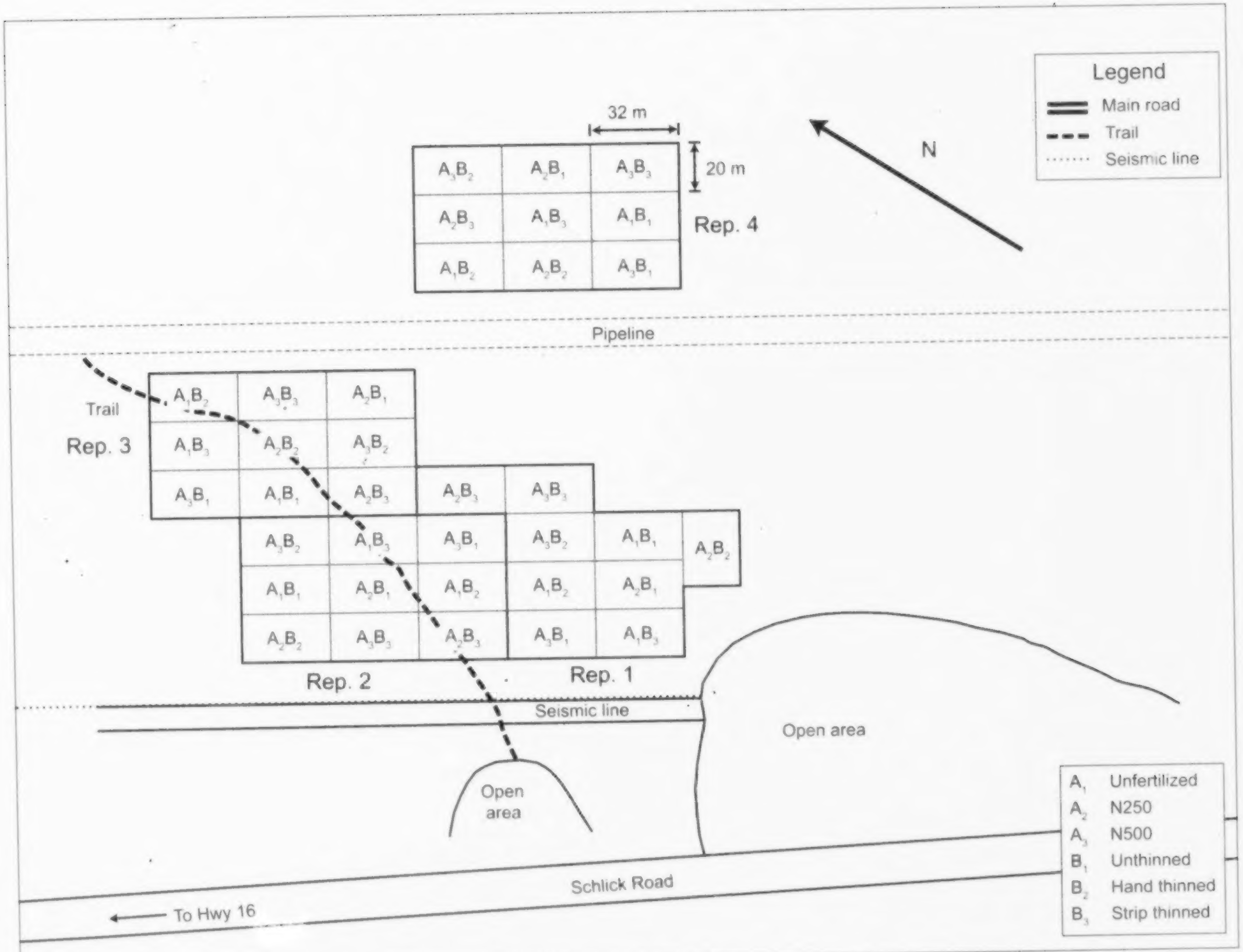
McCardell Creek Road fertilization and thinning trial (1984).


McCardell Creek Road
N
Legend
Road
Trail
Boundary line
Quad trail
Unthinned
Thinned
100 m
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72

McCardell Creek Road fertilization and thinning trial (1984).


N
Seismic line
Rep. 4
32 m
32 m
Legend
Main road
Trail
Seismic line
A_3B_3a
A_3B_3b
A_2B_1a A_3B_2a
A_2B_1b A_3B_2b
A_2B_1b A_1B_3 A_1B_2 A_3B_1b A_3B_3b A_2B_2a
A_2B_1a A_1B_3x A_1B_2x A_3B_1a A_3B_3a A_2B_2b
Rep. 3
A_3B_2b A_2B_3a A_1B_1x A_2B_2b A_1B_2x A_1B_3x A_2B_3a
A_3B_2a A_2B_3b A_1B_1 A_2B_2a A_1B_2 A_1B_3 A_2B_3b
A_3B_2b A_2B_1a A_1B_3x A_3B_1a A_1B_2 A_2B_3a A_1B_1
A_3B_2a A_2B_1b A_1B_3 A_3B_1b A_1B_2x A_2B_3b A_1B_1x
A_1B_1 A_1B_2x A_3B_1a A_1B_3 A_2B_1b A_3B_3a A_3B_1b
A_1B_1x A_1B_2 A_3B_1b A_1B_3x A_2B_1a A_3B_3b A_3B_1a
A_3B_3a A_2B_2a A_2B_3b A_3B_2b A_1B_1x A_2B_2a
A_3B_3b A_2B_2b A_2B_3a A_3B_2a A_1B_1 A_2B_2b
Rep. 1
Rep. 2
Schlick Road
← To Hwy 16
A_1 Unfertilized
A_1x PK only
A_2a N200 urea
A_2b N200 ammonium nitrate (or AN)
A_3a N400 urea
A_3b N400 ammonium nitrate
B_1 Unthinned
B_2 Hand thinned
B_3 Strip thinned

Takyi fertilization and thinning trial (1980), PSP 7008—medium productivity site.



32 m
20 m
N
Legend
Main road
Trail
Seismic line
A_3B_2
A_2B_1
A_3B_3
A_2B_3
A_1B_3
A_1B_1
Rep. 4
A_1B_2
A_2B_2
A_3B_1
Pipeline
Trail
A_1B_2
A_3B_3
A_2B_1
Rep. 3
A_1B_3
A_2B_2
A_3B_2
A_3B_1
A_1B_1
A_2B_3
A_2B_3
A_3B_3
A_3B_2
A_1B_3
A_3B_1
A_3B_2
A_1B_1
A_2B_2
A_1B_1
A_2B_1
A_1B_2
A_1B_2
A_2B_1
A_2B_2
A_3B_3
A_2B_3
A_3B_1
A_1B_3
Rep. 2
Rep. 1
Seismic line
Open area
Open area
Schlick Road
To Hwy 16
A_1 Unfertilized
A_2 N250
A_3 N500
B_1 Unthinned
B_2 Hand thinned
B_3 Strip thinned

Takyi fertilization and thinning trial (1980), PSP 7009—low productivity site.

Appendix 4

Top heights

This appendix presents top heights (m) for each treatment at each experimental site. The number in parentheses following the top height is the average number of trees per plot from which top heights were estimated. Using the usual 100 largest trees per hectare resulted in very low sample sizes because of small plot sizes in high-density treatments and because of missing height values where heights were subsampled. Therefore, the top heights in these tables were calculated using the 200 largest diameter trees per hectare. Even with this larger number of trees, many plots had only one or two top height trees; therefore, a minimum of three top height trees per plot was set, regardless of plot size.

Kananaskis Commercial Thinning Trial, Project K-57

Stand age (yr)	Thinned	Unthinned
85	14.2 (4)	17.2 (3)
99	16.2 (5.3)	19.0 (3.5)
135	21.4 (6)	21.3 (4)

MacKay Thinning Experiment, Project A-34

	Thinning treatment (stems per hectare)					
Stand age (yr)	750	1500	2600CT	2600	3700	Control
22*	7.2 (15)	6.1 (9.3)	6.5 (8.7)	6.3 (8.8)	6.3 (7)	5.9 (4.7)
28*	8.3 (14)	7.5 (10)	8.6 (8.7)	7.9 (8.3)	7.9 (6.7)	7.5 (5.3)
37*	11.7 (15)	10.0 (10)	12.4 (8.3)	10.9 (8.2)	11.0 (6)	10.5 (4.7)
47*	15.0 (15)	14.0 (8)	15.6 (8)	14.4 (7.5)	14.0 (5.3)	13.0 (5.3)
57*	17.8 (14)	16.4 (7.3)	17.8 (7.3)	16.5 (7)	16.3 (3.7)	15.0 (4.3)
64	20.1 (21)	18.3 (12)	19.1 (12.7)	18.6 (11.8)	18.6 (11)	17.1 (11.3)
71	21.4 (28)	19.3 (12)	20.4 (12.7)	19.4 (12.8)	19.6 (12)	18.1 (11.3)

*plot was subsampled.

Strachan Thinning Trial

	Thinning treatment			
Stand age (yr)	Crown thin	Low thin	Sanitation	Control
130	22.4 (16)	22.9 (16)	22.3 (16)	24.0 (16)
138	22.9 (16)	23.5 (16)	22.8 (16)	24.4 (16)

Swan Lake Thinning Experiment

	Thinning treatment						
Stand age (yr)	Barrel 1	Barrel 2	Chain 1	Chain 2	Disk 1	Disk 2	Control
10	1.7 (3)	1.4 (1)	1.7 (3)	1.5 (3.5)	1.7 (4)	1.5 (4)	1.9 (2)
16	3.5 (3.5)	3.2 (4)	3.5 (3.5)	3.6 (4)	3.8 (4)	3.8 (4)	4.0 (2)
21	5.6 (3.5)	6.1 (4)	5.8 (3.5)	6.0 (4)	6.1 (3.5)	6.3 (4)	6.4 (2)
27	7.4 (3.5)	8.4 (3.5)	7.3 (3)	8.0 (3.5)	8.3 (4)	8.5 (4)	8.3 (2)
36	11.8 (3.5)	11.7 (4)	12.3 (3.5)	12.1 (4)	12.6 (4)	12.7 (4)	12.7 (2)

Gregg Burn 1963 Spacing Experiment

		Thinning treatment (stems per hectare)					
Site	Stand age (yr)	500	1000	2000	4000	8000	Unthinned
Low productivity	15	2.0 (41)	2.0 (20)	2.0 (10)	2.1 (5)	2.2 (3)	
	20	3.9 (41)	3.9 (20)	3.9 (10)	3.7 (5)	3.5 (3)	
	25	6.2 (41)	6.1 (20)	6.0 (10)	5.8 (5)	5.6 (3)	
	30	7.8 (41)	7.8 (20)	7.5 (10)	7.3 (5)	6.6 (3)	
	35	9.5 (41)	9.6 (20)	9.3 (10)	9.3 (5)	8.7 (3)	
	40	10.9 (41)	11.0 (20)	10.9 (10)	10.8 (5)	10.4 (3)	8.1 (2)
	45	11.5 (41)	11.7 (20)	12.2 (10)	11.9 (5)	11.4 (3)	8.2 (2)
Medium productivity	15	3.4 (41)	3.6 (20)	3.5 (10)	3.1 (5)	3.2 (3)	
	20	5.4 (41)	5.4 (20)	5.5 (10)	4.9 (5)	5.2 (3)	
	25	7.4 (41)	7.5 (20)	7.7 (10)	7.0 (5)	6.9 (3)	
	30	8.9 (41)	9.0 (20)	9.3 (10)	8.5 (5)	8.8 (3)	
	35	10.4 (41)	10.7 (20)	10.9 (10)	9.6 (5)	9.6 (3)	
	40	11.8 (41)	12.3 (20)	12.1 (10)	11.5 (5)	11.7 (3)	
	45	12.5 (41)	13.0 (20)	13.1 (10)	11.4 (5)	11.8 (3)	
High productivity	15	3.8 (41)	4.1 (20)	3.9 (10)	4.2 (5)	4.3 (3)	
	20	5.7 (41)	6.0 (20)	5.9 (10)	6.0 (5)	6.3 (3)	
	25	7.7 (41)	8.0 (20)	7.9 (10)	8.2 (5)	8.3 (3)	
	30	9.2 (41)	10.0 (20)	9.7 (10)	9.5 (5)	9.3 (3)	
	35	11.0 (41)	11.6 (20)	11.4 (10)	11.5 (5)	11.2 (3)	
	40	12.2 (41)	13.3 (20)	13.2 (10)	12.8 (5)	12.0 (3)	12.4 (4)
	45	13.3 (41)	14.4 (20)	14.0 (10)	14.2 (5)	13.7 (3)	

Gregg Burn 1984 Spacing Experiment

		Thinning treatment (stems per hectare)				
Site	Stand age (yr)	1000	2000	3000	4000	Control
Low productivity	28	4.6 (20)	4.3 (10)	4.6 (8)	4.3 (5)	
	33	5.1 (20)	4.9 (10)	5.2 (8)	4.9 (5)	
	40	6.3 (20)	6.3 (10)	6.7 (8)	6.2 (5)	
	48	7.8 (20)	8.4 (10)	8.7 (8)	8.4 (5)	10.7 (2)
Medium productivity	28	7.9 (20)	8.6 (10)	8.3 (8)	8.5 (5)	
	33	8.8 (20)	9.7 (10)	9.6 (8)	9.6 (5)	
	40	10.6 (20)	11.2 (10)	11.5 (8)	11.3 (5)	
	48	13.4 (20)	13.8 (10)	14.0 (8)	14.1 (5)	12.0 (2)
High productivity	28	7.1 (20)	8.7 (10)	8.1 (8)	8.2 (5)	
	33	8.1 (20)	10.0 (10)	9.3 (8)	9.6 (5)	
	40	9.5 (20)	11.6 (10)	11.1 (8)	10.9 (5)	
	48	12.1 (20)	13.8 (10)	13.6 (8)	13.4 (5)	12.2 (2)

Teepee Pole Creek Spacing Experiment

		Thinning treatment (stems per hectare)					
Site	Stand age (yr)	500	1000	2000	4000	8000	Unthinned
Flat	26	7.1 (41)	7.6 (20)	7.6 (10)	7.8 (5)	7.9 (3)	
	31	7.9 (41)	8.6 (20)	9.0 (10)	9.0 (5)	9.6 (3)	
	36	9.1 (41)	10.0 (20)	10.9 (10)	10.7 (5)	11.3 (3)	
	41	10.6 (41)	11.5 (20)	12.7 (10)	12.4 (5)	13.1 (3)	
	46*	11.2 (26.5)	12.6 (14.5)	13.5 (5.5)	13.1 (3.5)	14.6 (2)	
	51*	12.1 (13.5)	13.4 (7)	14.9 (4)	14.8 (2)	14.8 (1.5)	
	55	14.0 (41)	15.2 (20)	16.4 (10)	16.3 (5)	16.1 (3)	16.6 (5.5)
	62	14.9 (41)	16.5 (20)	17.6 (10)	17.0 (5)	17.8 (3)	17.4 (5.5)
North	26	5.6 (41)	5.7 (20)	5.5 (10)	6.3 (5)	5.9 (3)	
	31	6.5 (41)	6.7 (20)	6.7 (10)	7.8 (5)	7.0 (3)	
	36	7.6 (41)	8.1 (20)	8.3 (10)	9.5 (5)	8.7 (3)	
	41	9.3 (41)	10.0 (20)	10.2 (10)	11.7 (5)	10.6 (3)	
	46*	10.1 (23)	11.1 (13.5)	11.3 (6)	12.4 (4.5)	11.4 (2.5)	
	51*	11.2 (14)	12.8 (5.5)	11.9 (3.5)	13.7 (3)	13.2 (2)	
	55	13.1 (41)	14.0 (20)	14.5 (10)	15.4 (5)	14.9 (3)	13.8 (5.5)
	62	14.6 (41)	15.8 (20)	16.0 (10)	16.9 (5)	16.2 (3)	15.7 (6)
South	26	7.7 (41)	8.2 (20)	7.6 (10)	8.6 (5)	7.2 (3)	
	31	8.4 (41)	9.4 (20)	8.3 (10)	10.0 (5)	8.0 (3)	
	36	9.0 (41)	10.7 (20)	9.4 (10)	11.7 (5)	8.8 (3)	
	41	10.3 (41)	12.4 (20)	10.8 (10)	13.2 (5)	9.8 (3)	
	46*	11.2 (25)	13.3 (13.5)	11.6 (6)	14.4 (2.5)	10.5 (2.5)	
	51*	12.3 (11.5)	14.5 (7)	13.0 (2.5)	14.6 (1)	10.9 (1)	
	55	13.2 (41)	15.7 (20)	13.8 (10)	16.3 (5)	12.2 (3)	17.6 (8.5)
	62	14.2 (41)	17.2 (20)	15.3 (10)	17.0 (5)	13.0 (3)	18.2 (8.5)

*plot was subsampled.

Clearwater Fertilization and Thinning Experiment

	Fertilization of thinned plots					
Stand age (yr)	N112	N112PS	N673	N673PS	Unfertilized	Unthinned
79	17.8 (4)	17.8 (4.3)	17.7 (3.3)	18.4 (4.7)	16.8 (3.7)	
100	17.9 (8)	18.0 (8)	18.4 (8)	18.4 (8)	18.3 (8)	
109	18.4 (8)	18.2 (8)	18.9 (8)	18.8 (8)	19.0 (8)	22.6 (22.3)

Ricinus Fertilization Trial

Stand age (yr)	Fertilization (kg/ha) N39P20	N79P41	Unfertilized
26	7.7 (4.5)	7.7 (3)	8.5 (4.5)
47	14.5 (8)	13.6 (8)	15.3 (8)
56	16.5 (8)	15.7 (8)	16.5 (8)

McCardell Creek Road Fertilization and Thinning Trial

Thinning treatment	Fertilization (kg/ha)	Stand age (yr) 40*	45*	50*	55*	60
Thinned	N0	13.2 (0.6)	14.1 (0.9)	14.6 (0.9)	16.5 (0.9)	17.8 (3.0)
	N180	13.9 (1.1)	14.7 (1.4)	15.8 (1.4)	17.1 (1.6)	18.0 (3.0)
	N360	13.9 (0.8)	14.6 (1.0)	15.8 (1.1)	16.7 (1.0)	17.8 (3.0)
	N540	13.4 (0.9)	14.3 (1.0)	15.2 (1.0)	16.7 (0.9)	17.9 (3.0)
Unthinned	N0	14.3 (1.1)	15.4 (1.1)	16.3 (1.1)	17.5 (1.2)	18.1 (3.0)
	N180	13.0 (1.0)	14.2 (1.0)	15.4 (1.0)	16.6 (0.9)	18.0 (3.0)
	N360	13.8 (0.8)	15.3 (0.9)	15.4 (0.9)	17.1 (0.9)	18.6 (3.0)
	N540	13.1 (0.9)	14.6 (0.8)	15.6 (0.7)	17.4 (0.7)	18.1 (3.0)

*plot was subsampled.

Takyi Fertilization and Thinning Trial (1980), PSP 7008—Medium Productivity Site

Thinning treatment	Fertilization (kg/ha)	Stand age 43
Hand thinned	N0PK	14.4 (3)
	N200-AN	13.3 (2)
	N200-U	14.4 (2.8)
	N400-AN	13.9 (2.8)
	N400-U	13.9 (3)
	Unfertilized	13.6 (2.5)
Unthinned	N0PK	14.4 (2.3)
	N200-AN	14.0 (2)
	N200-U	14.6 (2.3)
	N400-AN	15.0 (1.5)
	N400-U	15.7 (1)
	Unfertilized	14.0 (2.3)

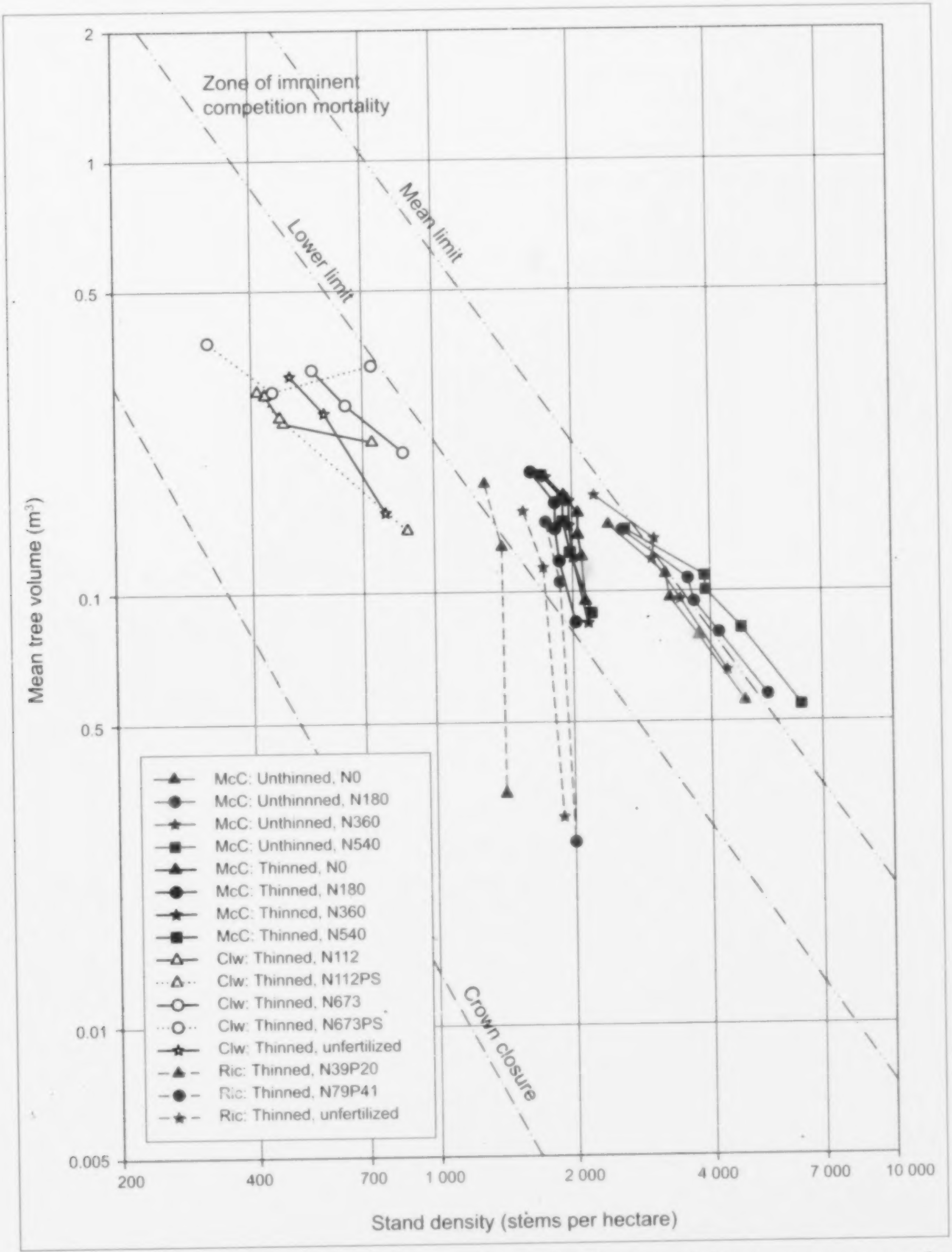
Takyi Fertilization and Thinning Trial (1980), PSP 7009—Low Productivity Site

Thinning treatment	Fertilization (kg/ha)	Stand age 43
Hand thinned	N250	12.9 (3.8)
	N500	12.1 (3.8)
	Unfertilized	12.7 (3.5)
Unthinned	N250	12.4 (3.3)
	N500	12.3 (2.8)
	Unfertilized	12.1 (2.3)

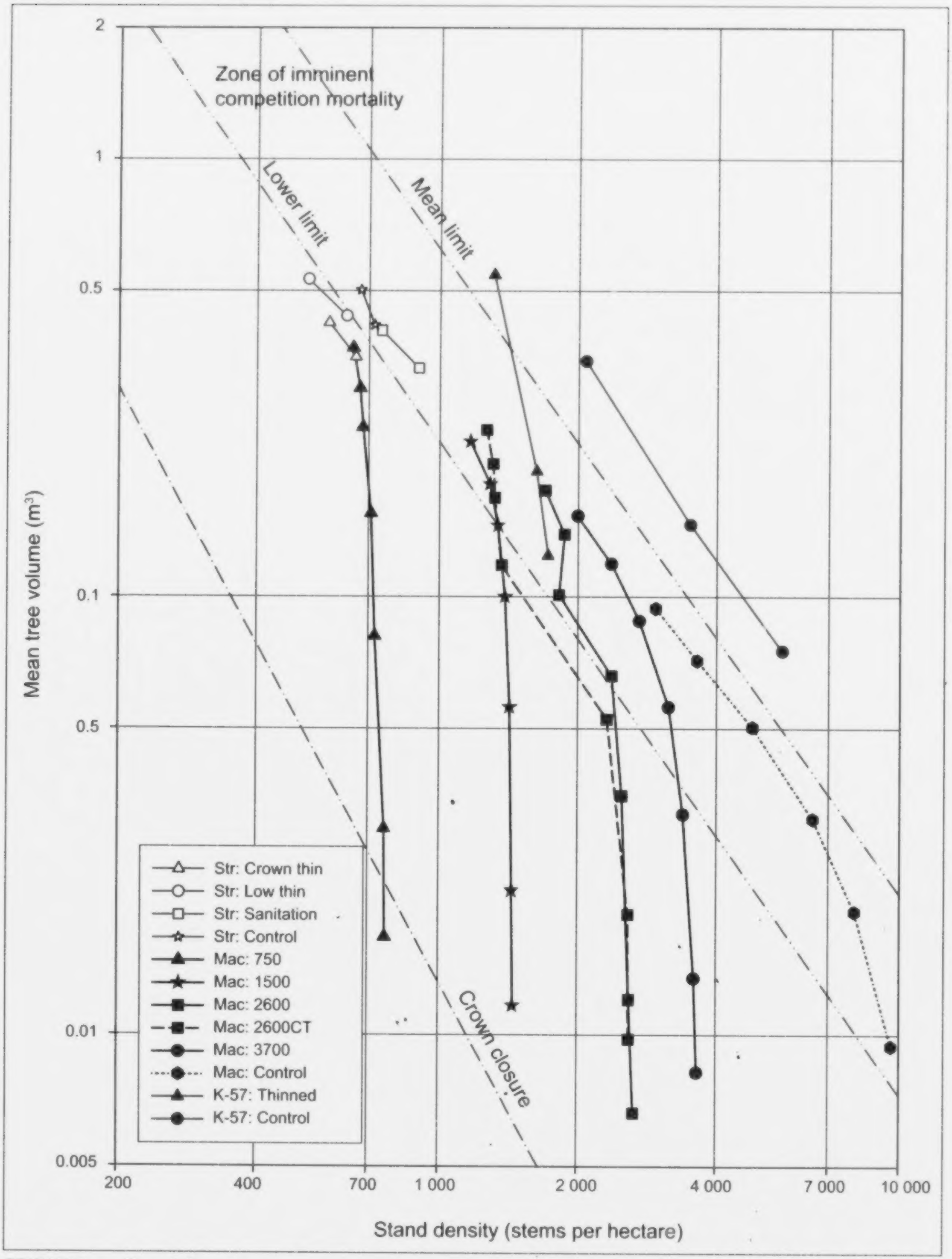
Appendix 5

Stand density management diagrams

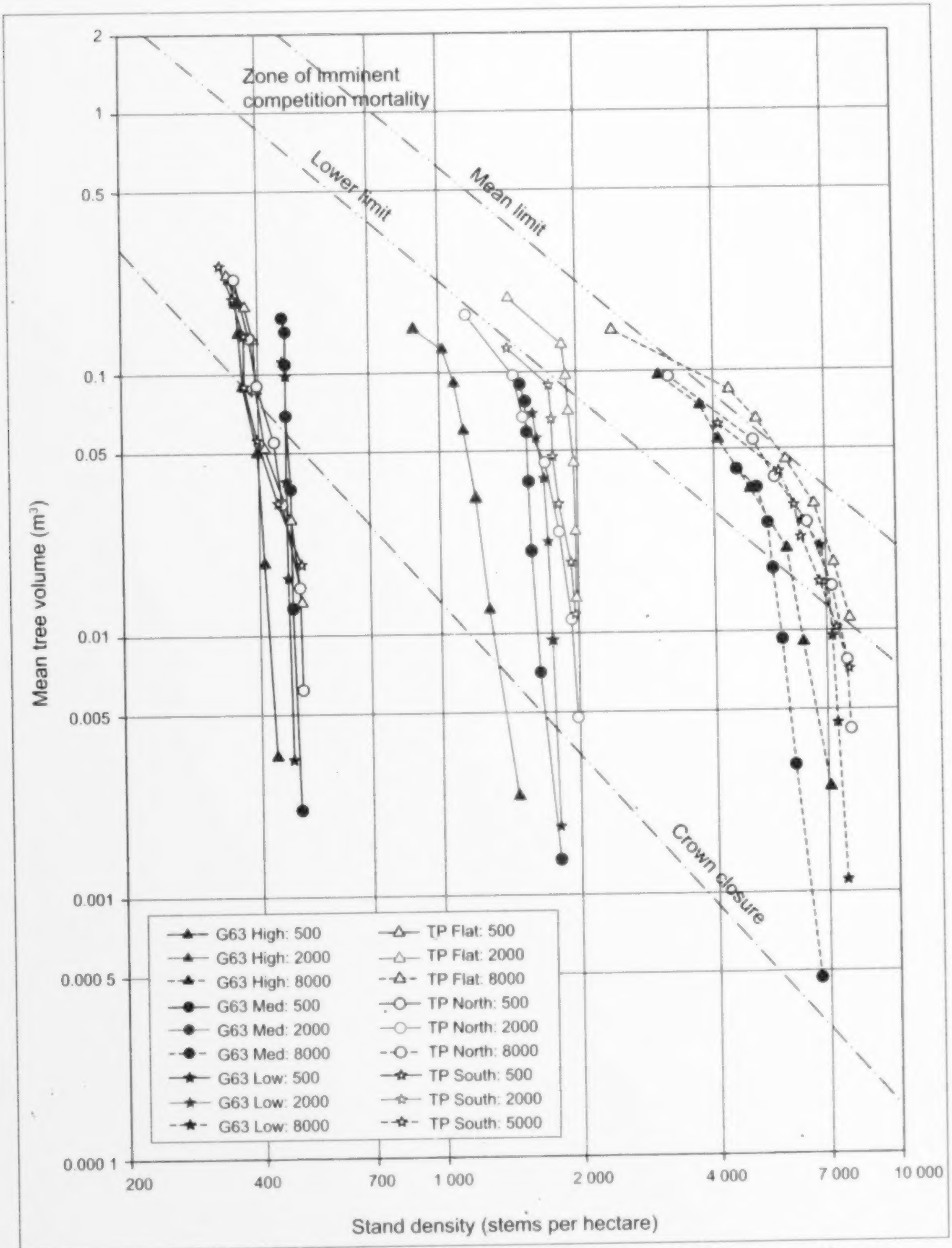
Simplified stand density management diagrams (SDMDs) are provided here to facilitate comparison of stand development among the various field studies. For the sake of legibility, not all treatment levels are included for each study. The diagrams are organized to compare the different fertilization studies (Fig. SDMD1), the thinning treatments carried out in older stands (Fig. SDMD2), the effects of site productivity and slope aspect in the same treatments carried out in the Gregg Burn 1963 and Teepee Pole experiments (Fig. SDMD3), and the effect of age of treatment for the same treatments in the Gregg Burn and two treatments from the Swan Lake study (Fig. SDMD4). The reference lines (crown closure, mean and lower limits of the zone of imminent competition mortality) are taken from Farnden (1996).



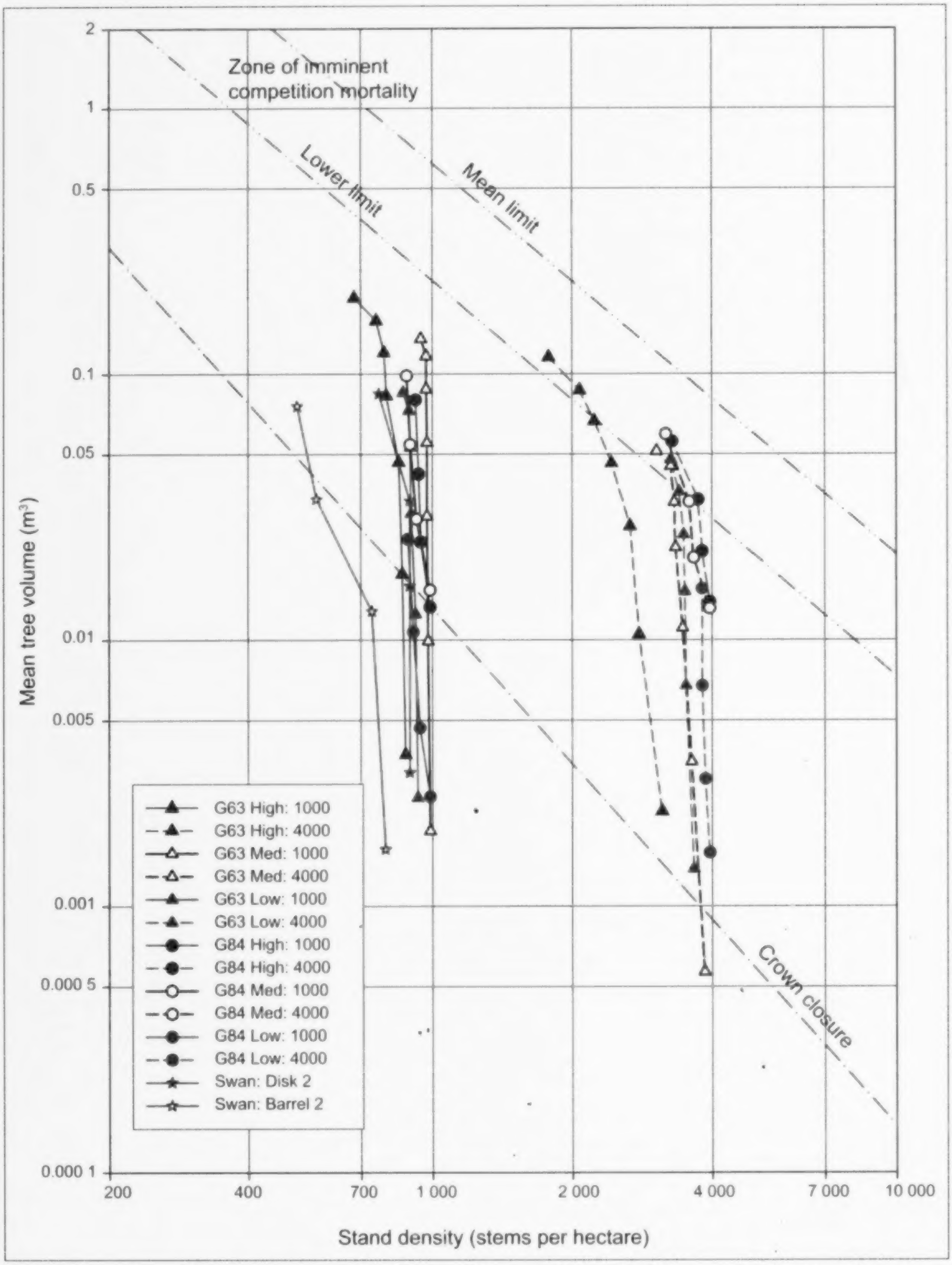
SDMD1. **Stand density management diagram for the fertilization and thinning treatments at the McCardell (McC), Clearwater (Clw), and Ricinus (Ric) sites.** Treatments are designated by level of nitrogen (N) and phosphorus (P) fertilization (as kilograms per hectare applied). S = sulfur.



SDMD2. Stand density management diagram for the thinning treatments at the Strachan (Str), MacKay (Mac), and K-57 sites. For the MacKay site, treatments are designated by stand density after thinning (stems per hectare); 2600CT = plot was rethinned to 70% of its basal area in 1969.



SDMD3. **Stand density management diagram for the 500, 2000, and 8000 stems per hectare thinning treatments at the Gregg Burn 1963 (G63) and Teepee Pole (TP) sites.**



SDMD4. **Stand density management diagram for the 1000 and 4000 stems per hectare thinning treatments at the Gregg 1963 (G63) and Gregg 1984 (G84) sites and for the two-way disk (Disc 2) and two-way barrel (Barrel 2) treatments at the Swan Lake (Swan) site.**